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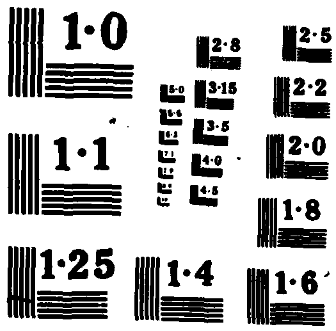
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ELECTRICAL AND THERMAL TRANSPORT
PROPERTY STUDIES OF HIGH-TEMPERATURE
THERMOELECTRIC MATERIALS: INTERIM
TECHNICAL REPORT FOR THE PERIOD
MAY 15, 1984 TO MAY 15, 1985

J. L. Bates
C. W. Griffin
W. J. Weber
L. C. Olsen*

June 1985

Prepared for
Air Force Office of Scientific Research
under AFOSR Contract #F49620-83-C0109

Battelle, Pacific Northwest Laboratories
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The research effort during this reporting period has continued to emphasize the study of electronically conducting oxides, which was initiated in the previous reporting period. The high-temperature transport property data base has been expanded by continued measurements in several systems under study, and a theoretical model for thermoelectric properties based on small polaron transport has been developed. The study of the transport properties of the In_2O_3-SnO_2 system, which was initiated during the previous reporting period, has been completed. Low values for the figure of merit were obtained, as expected, for

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these degenerate-type semiconductors.

Some high-temperature materials that exhibit small polaron conduction have the potential to exhibit high figures of merit. The theoretical model developed under this program predicts that narrow-band semiconductors with small polaron hopping along inequivalent sites of distorted sublattices can result in increases in both electrical conductivity and Seebeck coefficient with temperature without significant increases in thermal conductivity. High figures of merit, greater than 1.0 at 1000 K, that increase with temperature are predicted by the model. The model is being applied to the divalent metal-doped $(Y,La)CrO_3$ systems with the ABO_3 perovskite structure. Transport property data obtained during this reporting period for different divalent metal dopants at different concentrations are being used to evaluate the model.

Research will continue to emphasize the small polaron thermoelectric model. To verify and refine the model, experimental transport measurement studies will emphasize the effects of substitutions in the ABO_3 perovskite structure, particularly the distorted lattice developed by substitution on the B or O sites which increases inequivalent sites for hopping of small polarons. As a result of improvements in the thermal diffusivity apparatus, the effect of dopant on thermal conductivity will be investigated. The theoretical and experimental studies will be expanded to include the oxysulfides and sulfides, which should exhibit high electrical conductivity, high Seebeck coefficients, low thermal conductivity and, therefore, high figures of merit.

ELECTRICAL AND THERMAL TRANSPORT PROPERTY STUDIES OF HIGH-TEMPERATURE THERMOELECTRIC MATERIALS: INTERIM TECHNICAL REPORT FOR THE PERIOD MAY 15, 1984 TO MAY 15, 1985

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CONTENTS

1.0 SUMMARY 1.1

2.0 INTRODUCTION 2.1

3.0 TRANSPORT PROPERTY MEASUREMENTS 3.1

3.1 MEASUREMENT TECHNIQUES 3.1

3.2 SAMPLE PREPARATION 3.4

3.3 RESULTS 3.4

3.3.1 In_2O_3-SnO_2 . . . . 3.5

3.3.2 In_2O_3-PrO_2-ZrO_2 . . . . 3.6

3.3.3 ABO_3 Perovskites 3.8

4.0 THEORETICAL STUDIES 4.1

4.1 EVOLUTION OF MODEL 4.1

4.2 MODEL FOR SMALL POLARON TRANSPORT 4.1

4.2.1 Electrical Conductivity 4.3

4.2.2 Seebeck Coefficient 4.4

4.2.3 Possible Values of ZT for Small Polaron Materials . . 4.4

4.3 INTERPRETATION OF DATA FOR PEROVSKITES 4.7

5.0 FUTURE DIRECTION 5.1

6.0 REFERENCES 6.1

APPENDIX A - THERMOELECTRIC PROPERTY DATA A.1

<u>FIGURES</u>

3.1 Dimensionless Figure of Merit (ZT) as a Function of In_2O_3 Content 3.5

3.2 Electrical Conductivity of In_2O_3-PrO_2-ZrO_2 System 3.6

3.3 Seebeck Coefficient for the In_2O_3-PrO_2-ZrO_2 System 3.7

3.4 The Dimensionless Figure of Merit (ZT) for the In_2O_3-PrO_2-ZrO_2 System 3.8

3.5 The Log (σT) as a Function of Temperature in $(Y_{1-x}M_x)CrO_3$ System 3.9

3.6 Seebeck Coefficient as a Function of Temperature in $(Y_{1-x}M_x)CrO_3$ System 3.10

3.7 The Dimensionless Figure of Merit (ZT) as a Function of Temperature in $(Y_{1-x}M_x)CrO_3$ System 3.10

3.8 Log (σT) and S as a Function of Dopant Ionic Radius at 1000 K. 3.11

3.9 The Dimensionless Figure of Merit (ZT) as a Function of Dopant Ionic Radius 3.11

4.1 Schematic Illustration of Polaron Formation (A) and Electron Band Diagram for Small Polarons Located at Equivalent Sites (B) or at Inequivalent Sites (C) 4.2

4.2 Theoretically Calculated Seebeck Coefficient as a Function of Temperature 4.5

4.3 Theoretically Calculated Values for σT as a Function of 1/T 4.6

4.4 Theoretically Calculated ZT as a Function of Temperature . . . 4.6

4.5 Electron Band Structure for $YCrO_3$ (A) and $(Y_{1-x}M_x)CrO_3$ (B) . . . 4.7

4.6 Experimentally Determined Values for A in $(Y_{1-x}M_x)CrO_3$, and Theoretical Values for Both A and A' 4.9

4.7 Experimentally Determined Values of Overlap Integral J in $(Y_{1-x}M_x)CrO_3$ 4.10

TABLES

3.1 Sample Compositions 3.2

4.1 Transport Parameters for Chromites 4.8

1.0 SUMMARY

The research effort during this reporting period has continued to emphasize the study of electronically conducting oxides, which was initiated in the previous reporting period. The high-temperature transport property data base has been expanded by continued measurements in several systems under study, and a theoretical model for thermoelectric properties based on small polaron transport has been developed. The study of the transport properties of the In_2O_3-SnO_2 system, which was initiated during the previous reporting period, has been completed. Low values for the figure of merit were obtained, as expected, for these degenerate-type semiconductors.

Some high-temperature materials that exhibit small polaron conduction have the potential to exhibit high figures of merit. The theoretical model developed under this program predicts that narrow-band semiconductors with small polaron hopping along inequivalent sites of distorted sublattices can result in increases in both electrical conductivity and Seebeck coefficient with temperature without significant increases in thermal conductivity. High figures of merit, greater than 1.0 at 1000 K, that increase with temperature are predicted by the model. The model is being applied to the divalent metal-doped $(Y,La)CrO_3$ systems with the ABO_3 perovskite structure. Transport property data obtained during this reporting period for different divalent metal dopants at different concentrations are being used to evaluate the model.

Research will continue to emphasize the small polaron thermoelectric model. To verify and refine the model, experimental transport measurement studies will emphasize the effects of substitutions in the ABO_3 perovskite structure, particularly the distorted lattice developed by substitution on the B or O sites which increases inequivalent sites for hopping of small polarons. As a result of improvements in the thermal diffusivity apparatus, the effect of dopant on thermal conductivity will be investigated. The theoretical and experimental studies will be expanded to include the oxysulfides and sulfides, which should exhibit high electrical conductivity, high Seebeck coefficients, low thermal conductivity and, therefore, high figures of merit.

2.0 INTRODUCTION

The purpose of this report is to describe the technical results obtained during the second year of this continuing research project, covering the period from May 15, 1984 to May 15, 1985. The general objectives of this research investigation are to: a) develop theoretical models for electrical, thermal, and thermoelectric behavior of refractory oxide materials, b) determine electrical transport properties necessary to develop and test these models, c) determine methods for increasing the figure of merit in refractory oxide systems by varying composition, defect structure, microstructure, etc., and d) use these models to establish theoretical and empirical limits of the figure of merit for these oxides and other refractory materials.

During the first year of this project, existing data and theoretical models were extensively reviewed and evaluated. The research emphasized the initial measurements of high-temperature transport properties in the oxide systems based on the In_2O_3-SnO_2, (La,Y)(Mg,Ca,Sr)CrO_3, HfO_2-R_xO_y-In_2O_3, and La(Sr)MnO_3. This included the development of a novel technique for rapid, high-temperature determination of the absolute Seebeck coefficient. Based on the literature review and evaluation, the theoretical modeling effort concentrated on theories for the figure of merit and the transport properties of both broad-band and narrow-band semiconducting oxides, with particular emphasis on small polaron transport.

The research effort during this second year has continued to emphasize the determination of high-temperature transport property data that was initiated during the first year on several oxide systems. The theoretical modeling has focused on small polaron transport in narrow-band semiconducting oxides and has been applied to the divalent metal-doped (Y,La)CrO_3 system with the ABO_3 perovskite structure. These results, conclusions, and future research are described in the following sections of this report. In addition, the appendices contain tabulated data and the drafts of two papers being prepared for publication.

3.0 TRANSPORT PROPERTY MEASUREMENTS

The transport properties, which include the electrical conductivity, Seebeck coefficient, and thermal conductivity, were measured for the series of materials listed in Table 3.1. These materials include doped yttrium chromites, In_2O_3-SnO_2,[a] and ZrO_2-PrO_2-In_2O_3.[a] Although some chromite (ABO_3 perovskite) data were reported last year, the samples discussed in this report contained a wider range of A-site dopants and each sample was given a standardized heat treatment prior to the measurements. The chromite samples discussed in last year's report were not all prepared under standardized conditions, which led to some variation in transport properties.

3.1 MEASUREMENT TECHNIQUES

Generally, the same techniques described in last year's report were used to measure the transport data during this reporting period; however, some improvements were made in apparatus and software. The electrical conductivity was measured using the four-contact DC probe method. The electrical conductivity apparatus was modified to accommodate two samples for simultaneous measurements. Data obtained under identical conditions from two different samples can be readily compared. In addition, twice as many samples can be measured as before. This apparatus is presently being further modified for computer-controlled data acquisition.

The thermal conductivity was calculated from the product of the thermal diffusivity (determined by the flash technique), specific heat (determined by the rule of mixtures), and density. The thermal diffusivity apparatus has been directly interfaced with a computer during this reporting period. The modification allows data storage and preliminary calculation and graphic display of the thermal diffusivity during the series of measurements, which increases cost efficiency by identifying any data deficiencies. Final calculations are carried out after a complete data set is obtained.

(a) The fabrication, transport property, and crystallographic studies for these oxides were conducted in part under a U.S. Department of Energy contract by Battelle, Pacific Northwest Laboratories. The data are included because of their significance.

TABLE 3.1. Sample Compositions

Sample Identification	Composition
AF-14	$(La_{0.5}, Y_{0.5})_{0.98}Sr_{0.02}CrO_3$
AF-15	$(La_{0.5}, Gd_{0.5})_{0.98}Sr_{0.02}CrO_3$
AF-16	$(Y_{0.5}, Gd_{0.5})_{0.98}Sr_{0.02}CrO_3$
AF-17	$(Y_{0.99}, Ba_{0.01})CrO_3$
AF-18	$(Y_{0.98}, Ba_{0.02})CrO_3$
AF-19	$(Y_{0.95}, Ba_{0.05})CrO_3$
AF-20	$(Y_{0.98}, Sr_{0.02})CrO_3$
AF-21	$(Y_{0.95}, Sr_{0.05})CrO_3$
AF-22	$(Y_{0.925}, Sr_{0.075})CrO_3$
AF-23	$(Y_{0.90}, Sr_{0.10})CrO_3$
AF-24	$(Y_{0.85}, Sr_{0.15})CrO_3$
AF-25	$(Y_{0.95}, Ca_{0.05})CrO_3$
AF-26	$(Y_{0.875}, Ca_{0.125})CrO_3$
AF-27	$(Y_{0.85}, Ca_{0.15})CrO_3$
AF-28	$(Y_{0.98}, Mg_{0.02})CrO_3$
AF-29	$(Y_{0.90}, Mg_{0.10})CrO_3$
AF-30	$(Y_{0.85}, Mg_{0.15})CrO_3$
AF-36	$(La_{0.84}, Sr_{0.16})CrO_3$
AF-38	$(La_{0.84}, Sr_{0.16})(Al_{0.15}, Cr_{0.85})O_3$
AF-39	$(La_{0.9}, Ca_{0.1})(Al_{0.15}, Cr_{0.85})O_3$
AF-40	$La(Mg_{0.02}, Al_{0.15}, Cr_{0.83})O_3$
AF-41	$La(Mg_{0.02}, Al_{0.15}, Cr_{0.83})O_3$
AF-42	$(La_{0.9}, Ca_{0.1})(Al_{0.15}, Cr_{0.85})O_3$
FCCP-166	30 mol% PrO_2, 70 mol% ZrO_2
FCCP-54	9.0 mol% In_2O_3, 39.9 mol% PrO_2, 51.1 mol% ZrO_2
FCCP-144	75 mol% In_2O_3, 25 mol% ZrO_2
FCCP-160	18.2 mol% In_2O_3, 58.7 mol% PrO_2, 23.1 mol% ZrO_2
FCCP-93	20.1 mol% In_2O_3, 39.6 mol% PrO_2, 40.3 mol% ZrO_2
FCCP-52	23.0 mol% In_2O_3, 34.3 mol% PrO_2, 42.7 mol% ZrO_2
FCCP-51	36.6 mol% In_2O_3, 28.6 mol% PrO_2, 34.8 mol% ZrO_2

TABLE 3.1. Sample Compositions (Continued)

Sample Identification	Composition
FC-56	11.2 mol% In_2O_3, 89.8 mol% SnO_2
FC-57	16.3 mol% In_2O_3, 83.7 mol% SnO_2
FC-59	31 mol% In_2O_3, 69 mol% SnO_2
FC-125	40 mol% In_2O_3, 60 mol% SnO_2
FC-97-7	50 mol% In_2O_3, 50 mol% SnO_2
FC-126	60 mol% In_2O_3, 40 mol% SnO_2
FC-97-9	70 mol% In_2O_3, 30 mol% SnO_2
FC-97-10	80 mol% In_2O_3, 20 mol% SnO_2
FC-160	90.2 mol% In_2O_3, 9.8 mol% SnO_2

The novel apparatus developed on this program at Battelle to measure the Seebeck coefficient has not been changed; however, the computer program has been modified to properly correct for the emf of the Pt lead wires. In last year's report, the emf of the Pt lead wires was incorrectly subtracted from the voltage drop across the sample instead of added. (The data were not recalculated because of deficiencies in material preparation noted above). The apparatus and modified computer program were used to gather data and calculate the Seebeck coefficients of the materials listed in Table 3.1. In addition, the Seebeck coefficient of a Pt rod was determined for reference, and the measured data were within two percent of the data of Laubitz (1969) and Moore and Graves (1973).

The transport data for each property was fitted according to the following equations:

$$\log \sigma = A + B/T$$

$$\log (\sigma \times T) = A + B/T$$

$$\lambda = (A + BT)^{-1}$$

$$S = A + BT + CT^2 + DT^3$$

where σ is the electrical conductivity, 1/(ohm-cm), λ is the thermal conductivity, W/m-K, S is the Seebeck coefficient, μV/K, and T is the temperature, K. The coefficients A, B, C, and D (different for each property) were determined by fitting the appropriate equation to the data. The fitted coefficients and calculated transport properties are given in Appendix A for each composition tested. The equations for log σ and and log (σT) were fitted separately to the electrical conductivity data; consequently, the values for σ determined from

these equations will differ somewhat. The Seebeck coefficient was determined as a function of temperature using a third order polynomial, even though the model in Section 4.2 for small polaron-conducting materials proposes a linear relationship. The third order fit of the Seebeck coefficient was used in calculating the figure of merit because it gave the best fit for all data over the wide range of compositions and different conduction mechanisms.

The figure of merit (Z) and dimensionless figure of merit (ZT) were determined from the calculated equations for the transport properties by:

$$Z = \frac{S^2\sigma}{\lambda}$$

$$ZT = \frac{S^2\sigma}{\lambda} * T$$

The figures of merit are given in Appendix A.

3.2 SAMPLE PREPARATION

The In_2O_3-SnO_2 samples were prepared at Battelle by pressing and sintering coprecipitated powders. The details of the fabrication procedure are given in Appendix B. The ZrO_2-PrO_2-In_2O_3 samples were also fabricated at Battelle from coprecipitated powders using the same procedure.

The chromite samples (AF-14 to AF-30) were prepared by Harlan Anderson at the University of Missouri, Rolla, by pressing and sintering powders prepared by the liquid-mix method of Pechini (1967). Chromite samples AF-36 to AF-42 were obtained from Hugo Schmidt (1981) at Montana State University. These samples were prepared by either General Refractories Company or A-T Research Company. The exact preparation techniques for these samples are unavailable.

All of the chromite samples were heat treated in air at 1500°C for 48 h, followed by an additional 48 h in air at 1550°C. This heat treatment was necessary to fully oxidize the samples, since they were fabricated under reducing conditions.

3.3 RESULTS

The transport property data and calculated figures of merit for the In_2O_3-SnO_2, the In_2O_3-PrO_2-ZrO_2, and the ABO_3 perovskite systems are discussed in this section of the report. Additional data are contained in Appendix A.

3.3.1 In_2O_3-SnO_2

The study of the structure and transport properties of the In_2O_3-SnO_2 system was completed and a paper describing the results is attached, Appendix B. These materials were of interest due to their high electrical conductivity, which is greater than 1000 $(ohm-cm)^{-1}$ for compositions above 70 m/o In_2O_3. The electrical conductivity increased with the concentration of In_2O_3 and reached a maximum near 80 m/o In_2O_3. The Seebeck coefficient was negative for all compositions and became more negative as temperature increased. The Seebeck coefficient varied with composition; below 40 m/o In_2O_3, the Seebeck coefficient was between -50 and -60 μV/K at 1000 K. From 40 to 80 m/o In_2O_3, the Seebeck coefficient decreased from -100 to -30 μV/K with increasing In_2O_3 concentration. The Seebeck coefficients increased slightly to -60 μV/K at 90 m/o In_2O_3. As the Seebeck coefficient decreased, the electrical conductivity increased. The dimensionless figure of merit (ZT) increased with the In_2O_3 content and reached a maximum of 0.2 for 70 m/o In_2O_3 at 1200 K, as shown in Figure 3.1. The dimensionless figure of merit decreased significantly for the 80 m/o In_2O_3 composition due to an order of magnitude increase in thermal conductivity. The increase in thermal conductivity was probably due to the contribution of the electronic component to thermal conductivity, which was negligible for the other compositions. The small negative Seebeck coefficient indicates that this material

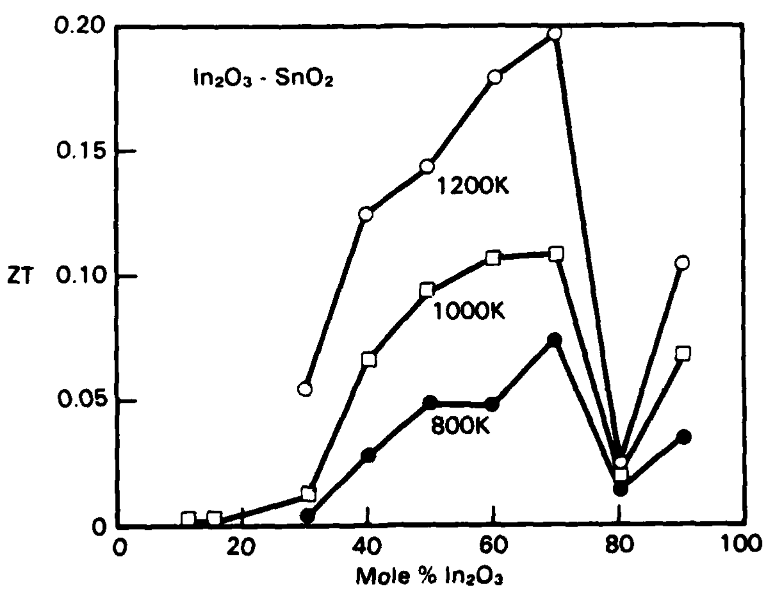

FIGURE 3.1. Dimensionless Figure of Merit (ZT) as a Function of In_2O_3 Content

behaves as a degenerate semiconductor. The compositions exhibiting the highest ZT values from 40 to 70 m/o In_2O_3 appear to be structurally related to the rhombohedral $In_4Sn_3O_{12}$ (40 m/o) composition. A minor noncrystalline phase present in this same composition range may also be affecting the behavior. The minimum values of ZT near 80 m/o In_2O_3 are related to the body-centered-cubic (bcc) solid solution limit of SnO_2 in In_2O_3.

3.3.2 In_2O_3-PrO_2-ZrO_2

Depending on the composition and structure, this system can exhibit high electrical conductivity with negative Seebeck coefficients or low electrical conductivity with high positive Seebeck coefficients, as illustrated in Figures 3.2 and 3.3. The structure of this system consists of a number of phases, the most important being a body-centered-cubic (bcc) In_2O_3 phase, which brings about the high electrical conductivity. In the absence of the bcc phase, the electrical

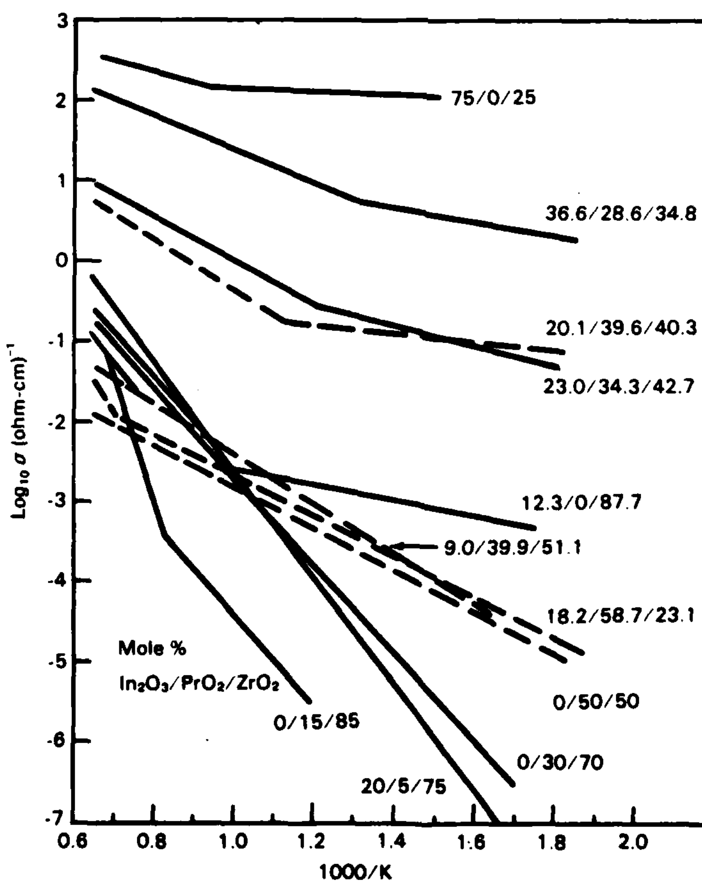

FIGURE 3.2. Electrical Conductivity of In_2O_3-PrO_2-ZrO_2 System

conductivity of this system (primarily a pyrochlore, $Zr_2Pr_2O_7$, and orthorhombic $Pr_2In_2O_7$) was low with high positive Seebeck coefficients indicating ionic conduction similar to cubic ZrO_2. The dimensionless figure of merit was less than 0.01 for these ionically conducting compositions. Similar behavior has been observed in the isomorphic structure of In_2O_3-PrO_2-HfO_2.

Compositions containing the bcc phase had high electrical conductivity with negative Seebeck coefficients between 80 and 120 mV/K that became more negative with increased temperature. As the electrical conductivity increased, the dimensionless figure of merit increased. A maximum value for ZT of 0.18 was calculated at 1300 K for 75 In_2O_3-25 ZrO_2, as shown in Figure 3.4. All these compositions behave similar to a degenerate semiconductor. Additional information on these materials is given in Appendix A.

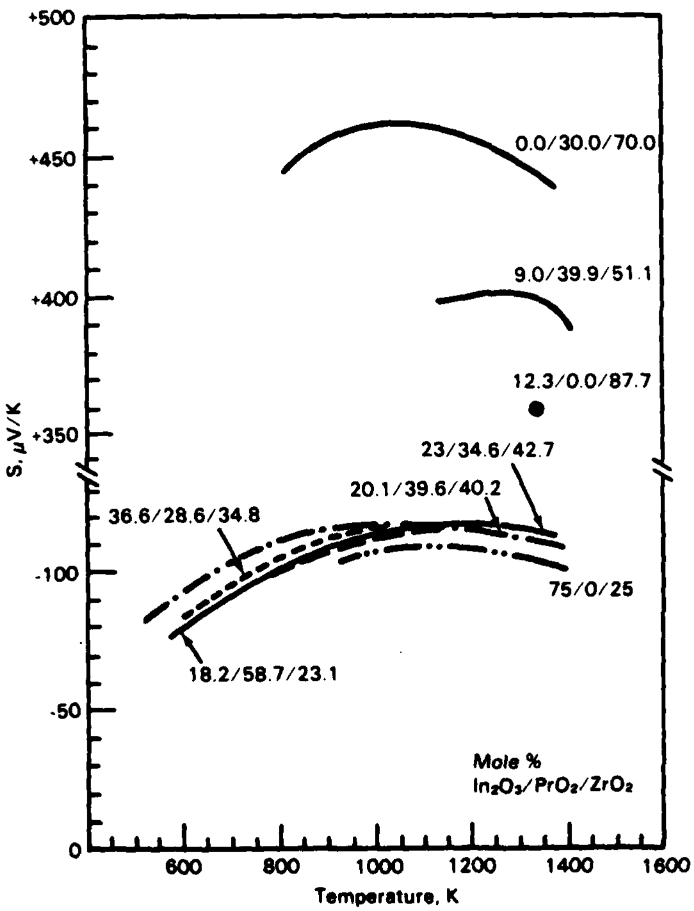

FIGURE 3.3. Seebeck Coefficient for the In_2O_3-PrO_2-ZrO_2 System

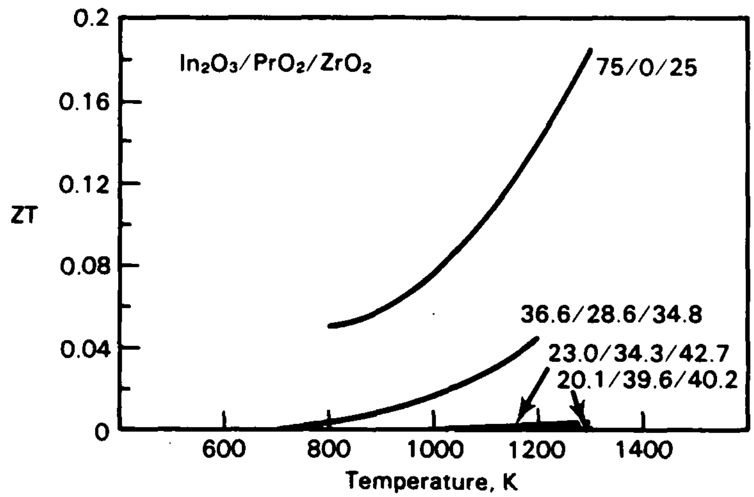

FIGURE 3.4. The Dimensionless Figure of Merit (ZT) for the In_2O_3-PrO_2-ZrO_2 System

3.3.3 ABO_3 Perovskites

Electrical conductivity and Seebeck coefficient measurements have been carried out on all the ABO_3 materials received (and heat treated) this year. Thermal diffusivity measurements were delayed because of the upgrade in the apparatus, but are currently being carried out and will be reported in the next interim report. The log (σT) decreased nearly linearly with inverse temperature and the positive Seebeck coefficient increased nearly linearly with temperature, both in agreement with the model for small polaron transport (discussed later). The maximum values for the figure of merit, ZT, at 1000 K were on the order of 0.015 to 0.020. All of the results are tabulated in Appendix A.

An extensive investigation of the divalent-metal-doped $(Y_{1-x}M_x)CrO_3$ series of materials (M = Mg, Ca, Sr, Ba) was carried out during the reporting period. Characterization of the materials by optical and electron microscopy and x-ray diffraction (XRD) indicates that a second phase forms when x = 0.15 and suggests that the solubility limit for the dopants is less than 0.15. Consequently, the data for samples with x = 0.15 are to be viewed with some suspicion due to the unknown effects of the second phase. In addition (as discussed later), a significant fraction of Mg may actually substitute for Cr on the B-site, due to the smaller ionic radius of Mg^{+2}, which is similar in size to Cr^{+3}.

The electrical conductivity, σ, results for $(Y_{1-x}M_x)CrO_3$ series of materials are shown in Figure 3.5. The log (σT) decreased linearly with inverse temperature, in agreement with the theoretical model for small polaron transport (Section 4.2.1). The electrical conductivity generally increased with the amount of dopant and was maximized with Ca as the dopant. The Seebeck coefficient for these same materials increased nearly linearly with temperature, as shown in Figure 3.6, also in agreement with the model (Section 4.2.2). The Seebeck coefficient generally decreased with the amount of dopant and was minimized with Ca as the dopant. The dimensionless figure of merit, ZT, increased with temperature as shown in Figure 3.7, for several of these materials. The largest values of ZT occurred with Ca as the dopant.

The effects of the different dopant species are more clearly indicated in Figures 3.8 and 3.9, where log (σT), S, and ZT at 1000 K are shown as a function of ionic radius of the dopant. A rather sharp peak (σ, ZT) or valley (S) occurs when Ca is the dopant. This behavior can be attributed to the similar ionic radius of Ca^{+2} and Y^{+3}, as indicated in Figures 3.4 and 3.5. As the ionic radius of the divalent dopant deviates from that of Y^{+3}, more lattice distortion can be expected, with generally detrimental effects. This suggests that maximum performance probably occurs when the ionic radius of any dopant is close to that of the substituted ion. This hypothesis will be explored further in future work and helps to more clearly define the compositions to be studied.

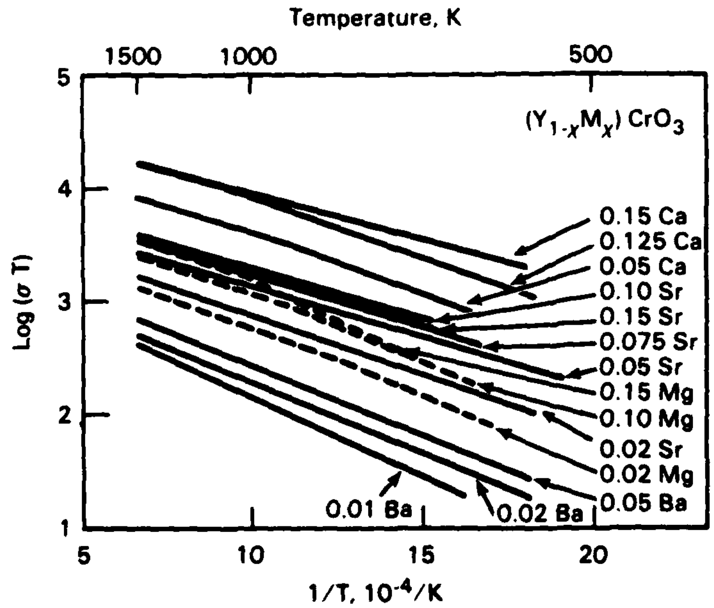

FIGURE 3.5. The Log (σT) as a Function of Temperature in $(Y_{1-x}M_x)CrO_3$ System

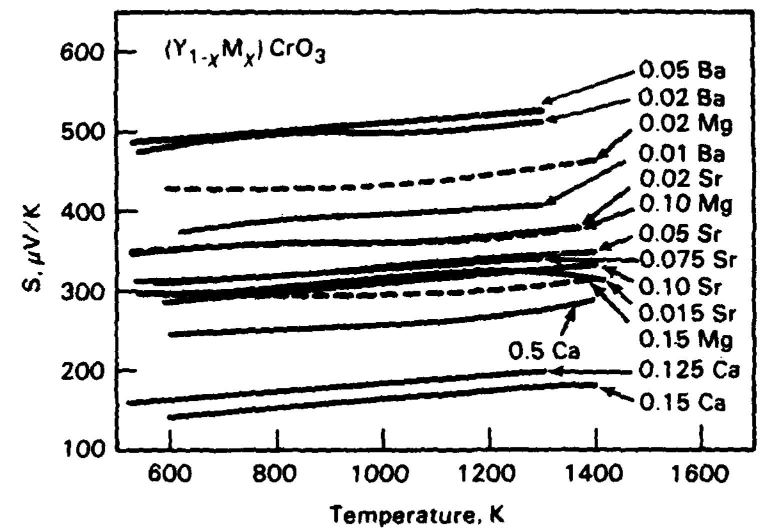

FIGURE 3.6. Seebeck Coefficient as a Function of Temperature in $(Y_{1-x}M_x)CrO_3$ System

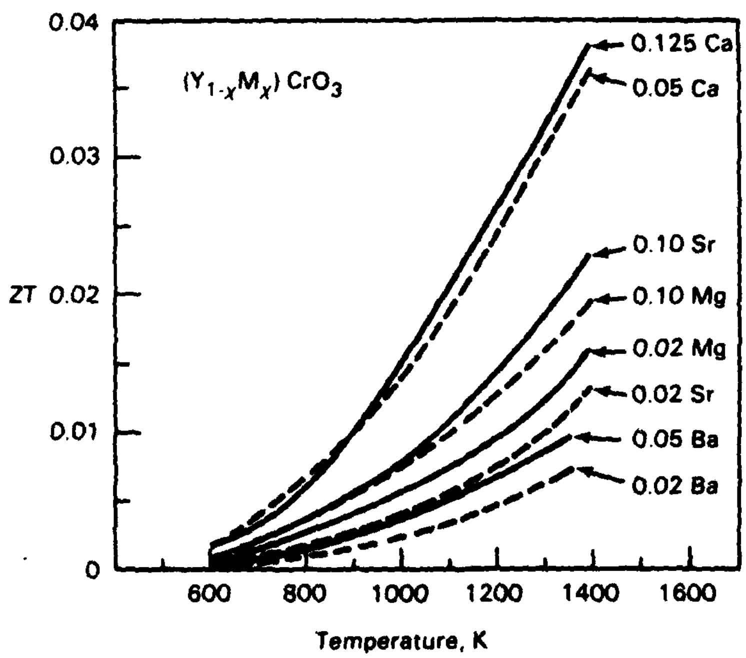

FIGURE 3.7. The Dimensionless Figure of Merit (ZT) as a Function of Temperature in $(Y_{1-x}M_x)CrO_3$ System

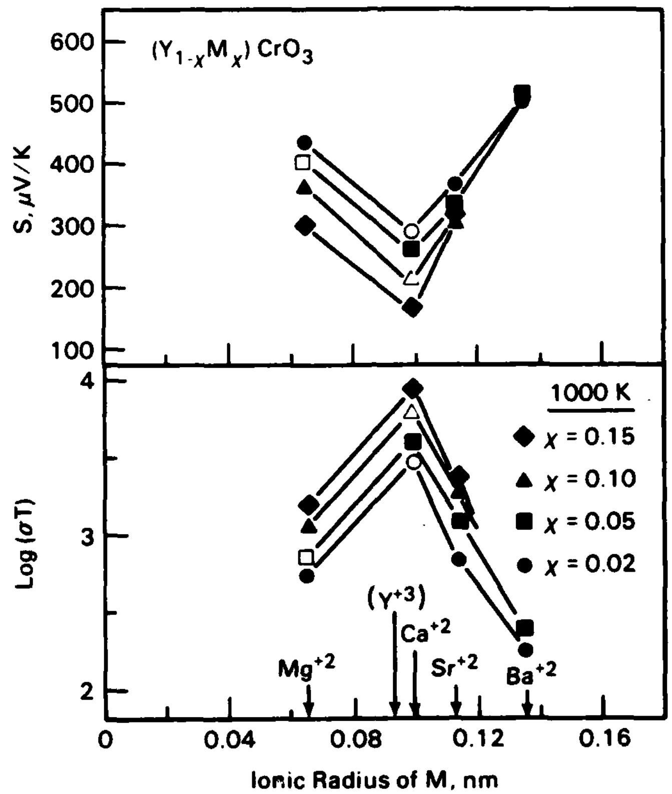

FIGURE 3.8. Log (σT) and S as a Function of Dopant Ionic Radius at 1000 K. Open data points are based on linear interpolation or extrapolation.

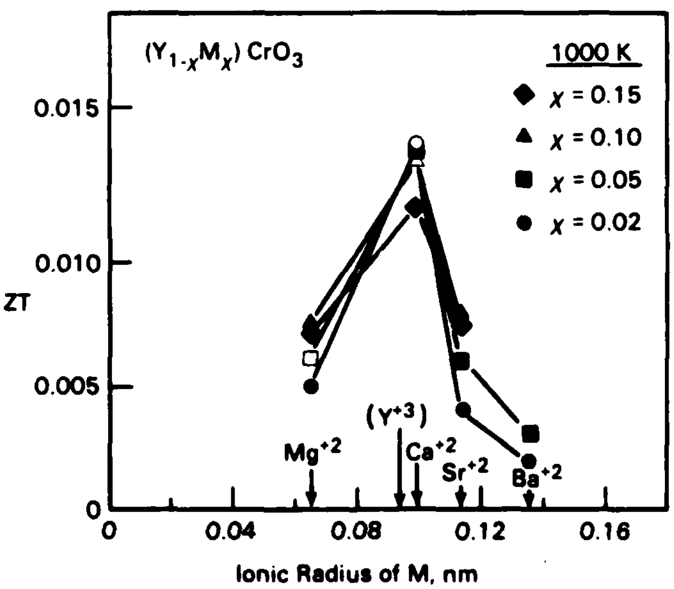

FIGURE 3.9. The Dimensionless Figure of Merit (ZT) as a Function of Dopant Ionic Radius

4.0 THEORETICAL STUDIES

4.1 EVOLUTION OF MODEL

During the first year of this program, several oxide materials were investigated as potential thermoelectric materials. Since oxides typically exhibit small polaron conduction, theoretical studies of small polaron conductors were begun. Initial efforts concentrated on literature review and the development of analytical expressions for thermoelectric properties of small polaron materials. During the current year, a fairly detailed theory for the thermoelectric properties of small polaron materials has been developed. The resulting model is used to carry out calculations of the figure of merit. In addition, the model has been used to interpret experimental data for the $(Y_{1-x}M_x)CrO_3$ perovskites.

In the following sections, the model for small polaron transport is discussed, data for perovskites are interpreted in terms of the developed model, and modeling calculations for ZT are presented.

4.2 MODEL FOR SMALL POLARON TRANSPORT

A small polaron refers to a localized electron state. The electron state is typically localized over a region on the order of a lattice constant. Figure 4.1A presents a rather simple picture of such a state. Each ion is surrounded by an "electron cloud" except the one located at the center, where an orbital electron is missing from the center ion. As a result, the outer electrons of the adjacent ions are attracted toward the center ion, and the energy level of the empty electron state associated with the center ion is increased. The raised energy level is shown in Figure 4.1B as an amount E_{BO} above the filled energy band. A "hole" is shown residing in this state. If an electron fills the state, the energy level will be lowered to the top of the energy band. The hole (absence of electron) can move through the lattice. A small polaron is shown hopping between equivalent sites in Figure 4.1B. This process can, of course, be viewed as a normal orbital electron hopping from right to left. Figure 4.1C describes small polarons located at inequivalent sites. As noted in Figures 4.1A and 4.1B, energy is exchanged with the lattice during these hopping processes.

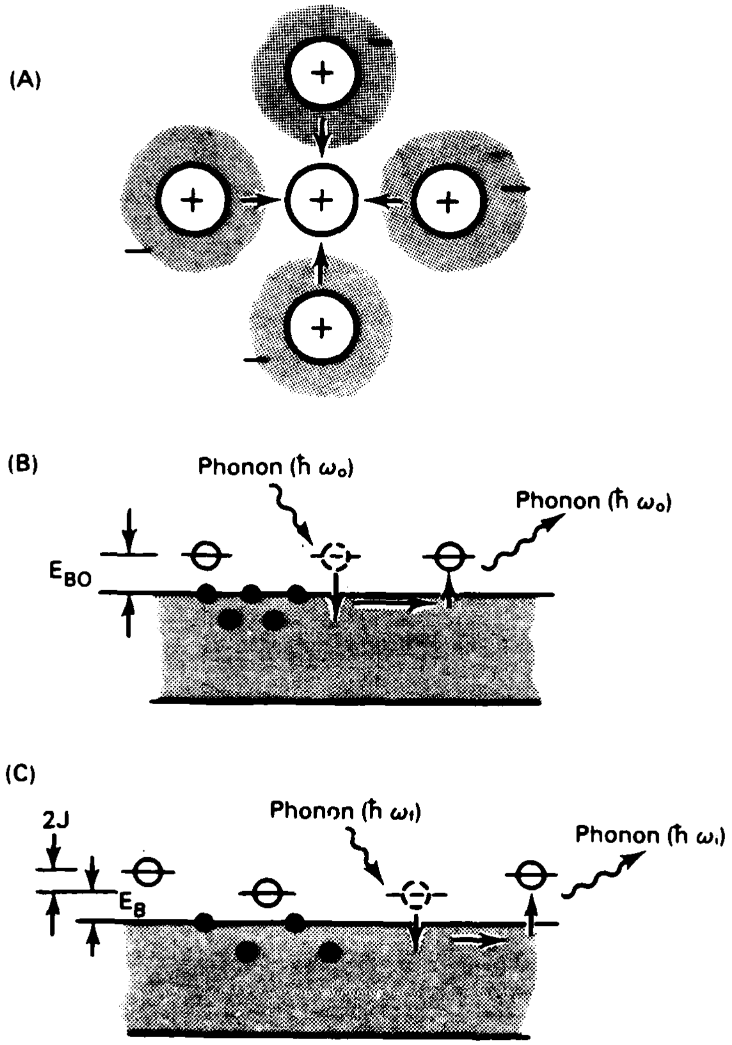

FIGURE 4.1. Schematic Illustration of Polaron Formation (A) and Electron Band Diagram for Small Polarons Located at Equivalent Sites (B) or at Inequivalent Sites (C).

4.2.1 Electrical Conductivity

The electrical conductivity due to small polaron transport is given by

$$\sigma = ne\mu,$$

where

n = small polaron concentration,

e = electronic charge,

μ = mobility.

The mobility, μ, is given by

$$\mu = (1-x)\left(\frac{ea_o^2\nu}{kT}\right) \exp\left(\frac{-E_a}{kT}\right),$$

where

E_a = activation energy

a_o = distance between sites

ν = optical phonon frequency

x = fraction of sites occupied by small polarons

The activation energy, E_a, is the minimum energy that must be supplied to displace those atoms about the initial and final sites so as to establish a coincident event, that is, to cause the electron energy level at the small polaron site and the electron level at a neighboring site to be coincident. The value of E_a is estimated to be on the order of $E_B/2$, where E_B is the binding energy of the polaron. For hops on the order of 4 Å, the pre-exponential factor in the expression for μ is approximately 1 cm^2/V-sec. Thus, small polarons exhibit low values of drift mobility.

The electrical conductivity due to small polaron transport can be fairly large, since the density of carriers can approach the density of atoms in the system. Let N_o be the density of atoms at which the small polarons may be located, and let x refer to the fraction of these atoms at which small polarons actually exist. The small-polaron density is then given by $n = xN_o$.

4.2.2 Seebeck Coefficient

The Seebeck coefficient (S) is the average energy transferred by a carrier (Peltier heat) divided by eT. S has two terms; one term is related to the location of the Fermi level, that is, the density of carriers. The second term is dependent on the nature of the polaron hopping mechanism. The Seebeck coefficient can be written as

$$S = A + BT ,$$

where

$$A = \left(\frac{k}{e}\right) \ln \left(\frac{2(1-x)}{x}\right)$$

$$B = \left(\frac{k}{e}\right) \frac{z\ J^2 k}{E_B^3} = \left(\frac{k}{e}\right) \frac{z\ J^2 k}{(E_{BO} - J)^3} ,$$

and E_B has been estimated to be $E_{BO} - J$, z is number of nearest available sites for hopping, and J is the overlap integral.

The A-term has always been included in past treatments of small-polaron transport theory. Recent work by Emin and Wood (1983) has led to the addition of the B-term. Thermoelectric studies of boron-carbides revealed that S varied linearly with temperature, and Emin and Wood determined that if hopping occurs between inequivalent sites the B-term results, which can be very significant for some thermoelectric materials. If the B-term is large, the Seebeck coefficient increases dramatically with temperature. Since the figure of merit varies as S^2, the material can exhibit a significant increase in ZT with temperature.

4.2.3 Possible Values of ZT for Small Polaron Materials

Ure (1972) has calculated potential values of the figure of merit for broad-band materials. He concluded that ZT may approach values on the order of 2 or 3. Heikes and Ure (1961) also examined the potential value of ZT for narrow-band materials. They concluded that ZT for these materials may approach 0.2 or 0.3. However, Heikes and Ure did not account for the B-term in their study. Calculations of ZT for small polaron materials that include the effect of hopping between inequivalent sites are presented in this section.

The following parametric values (typical of perovskites) were assumed in these calculations:

thermal conductivity = 1.0 W/m-K

$$N_o = 7.5 \times 10^{27} m^{-3}$$
$$\nu = 2 \times 10^{13} \text{ Hz}$$
$$a_o = 0.5 \text{ nm}$$
$$z = 6$$
$$E_{BO} = 0.2 \text{ eV}$$

Values of the fraction of sites occupied (x), and the overlap integral (J), were varied to give parametric plots of ZT. The range of these parameters are:

$$0 < x < 1.0$$
$$0 < J < 1.0$$

Calculations of possible values of S are given as a function of temperature in Figure 4.2, while calculated values of the electrical conductivity versus T are presented in Figure 4.3. These calculated values are combined with the assumed value for thermal conductivity to give ZT versus T in Figure 4.4. It appears that ZT values greater than 1.0 are quite possible for small polaron materials. Two key effects are required: large values of x to give an adequate electrical conductivity and a finite value for J, that is, hopping between inequivalent sites.

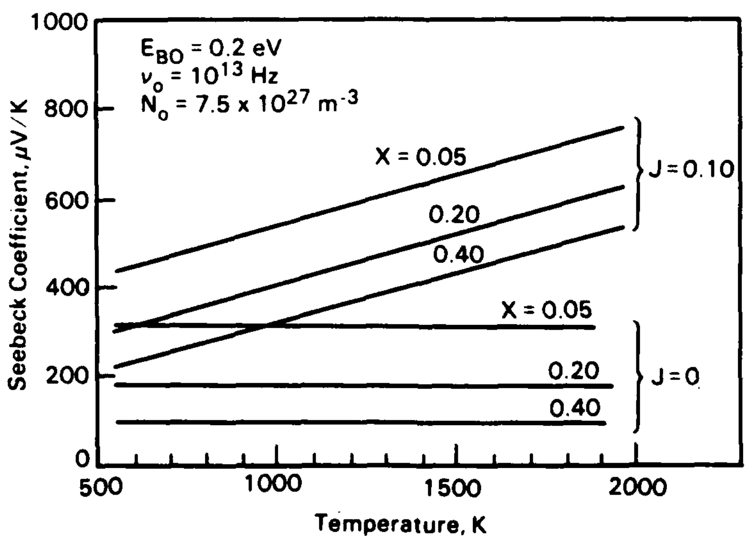

FIGURE 4.2. Theoretically Calculated Seebeck Coefficient as a Function of Temperature

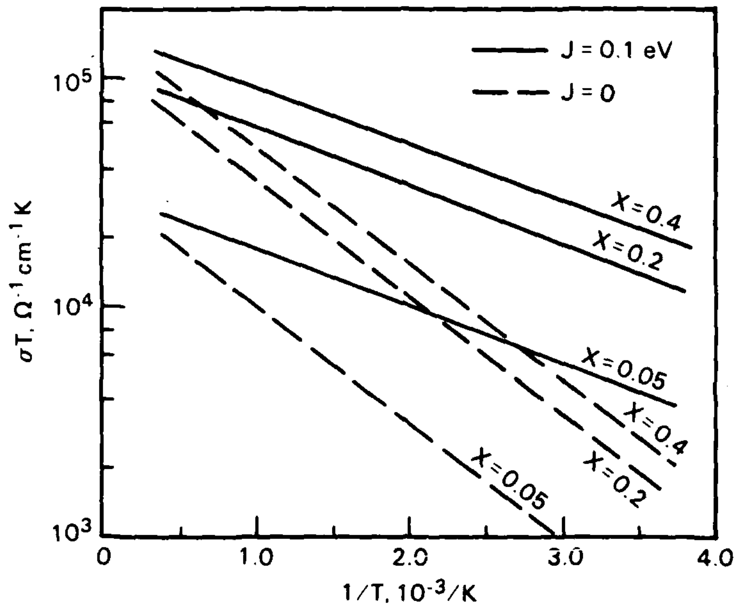

FIGURE 4.3. Theoretically Calculated Values for σT as a Function of 1/T

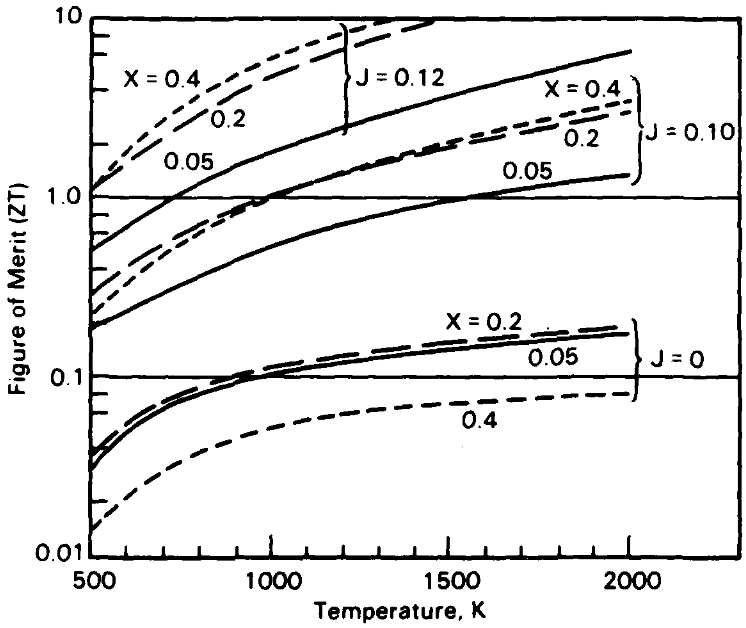

FIGURE 4.4. Theoretically Calculated ZT as a Function of Temperature

4.3 INTERPRETATION OF DATA FOR PEROVSKITES

Several different perovskite materials (ABO_3) were studied this past year. The $Y_{1-x}M_xCrO_3$ series with M = Mg, Ca, Sr and Ba was investigated in detail. These materials are assumed to have an electron band diagram described by Figure 4.5A. The π-band is a narrow band with a tendency toward localization. Figure 4.5B describes the expected band structure when divalent ions are substituted on the A-lattice. The divalent ion causes a hole to be formed in the π-band. The hole is localized and is thus a small polaron state. The hole is assumed to be in the form of a Cr^{4+} ion.

Electrical conductivity data were acquired for temperatures between 500 K to 1400 K. The electrical conductivity and Seebeck coefficient exhibit temperature dependence consistent with small polaron theory. Thus, σ and S can be expressed by the following relationships:

$$\sigma = \sigma_o T^{-1} \exp(-E_a/kT)$$

$$S = A + BT$$

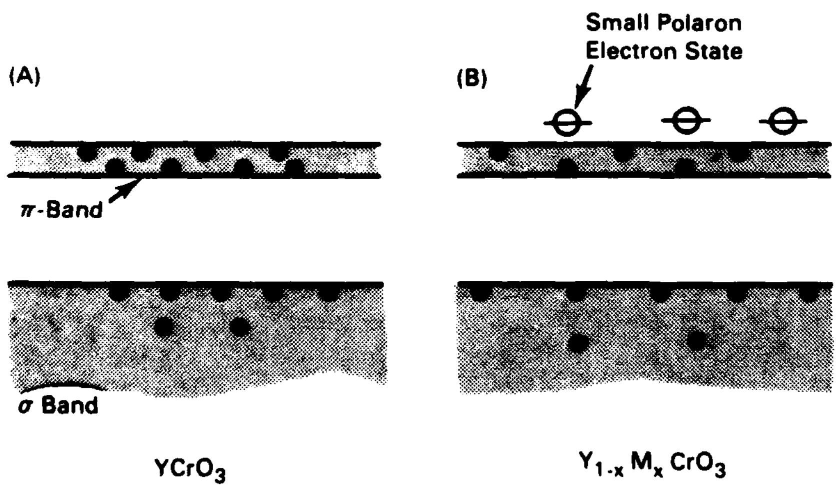

FIGURE 4.5. Electron Band Structure for $YCrO_3$ (A) and $(Y_{1-x}M_x)CrO_3$ (B)

Transport parameters deduced by interpreting the data for σ and S in terms of the above expressions are tabulated in Table 4.1. Consider the materials for which Ca, Sr and Ba have been substituted on the A site. For a given value of x, the parameter A increases with the ionic radius of the dopant M. Since this term primarily depends on the location of the Fermi level, the actual value of x must be less than the intended value. Figure 4.6 describes the A-values obtained for these materials versus x. The behavior of A for all materials is in qualitative agreement with theory. The material for which the data deviate the most is $Y_{1-x}Ba_xCrO_3$. Both A and B increase with x. This behavior is not yet understood. Although the electrical conductivity is relatively low, it is also increasing with x; thus, the $Y_{1-x}Ba_xCrO_3$ should be investigated further.

Referring to Figure 4.6, the A and A' are theoretical quantities defined by

$$A = \left(\frac{K}{e}\right) \log_e \left(\frac{2(1-x)}{x}\right)$$

$$A' = \left(\frac{K}{e}\right) \log_e \left(\frac{(1-x)}{x}\right)$$

TABLE 4.1. Transport Parameters for Chromites

Compound	x	σT @ 1000 K (ohm^{-1} cm^{-1} K)	E_a (eV)	A ($\mu V/K$)	B ($\mu V/K^2$)	J (eV)
$Y_{1-x}Ba_xCrO_3$	0.01	139	0.238	356	0.0394	0.0546
	0.02	190	0.256	460	0.0426	0.0634
	0.05	261	0.251	461	0.0489	0.0659
$Y_{1-x}Sr_xCrO_3$	0.02	770	0.205	323	0.0427	0.0455
	0.05	1337	0.180	283	0.0474	0.0394
	0.075	1669	0.187	281	0.0459	0.0411
	0.1	1932	0.182	262	0.0498	0.0411
	0.015	1755	0.193	279	0.0319	0.0359
$Y_{1-x}Ca_xCrO_3$	0.05	3420	0.208	204	0.0561	0.0532
	0.125	7768	0.201	134	0.0449	0.0453
	0.15	8800	0.173	110	0.0530	--
$Y_{1-x}Mg_xCrO_3$	0.02	542	0.234	370	0.0700	0.0710
	0.10	1060	0.225	300	0.0569	0.0603
	0.15	1354	0.256	276	0.0241	0.0477

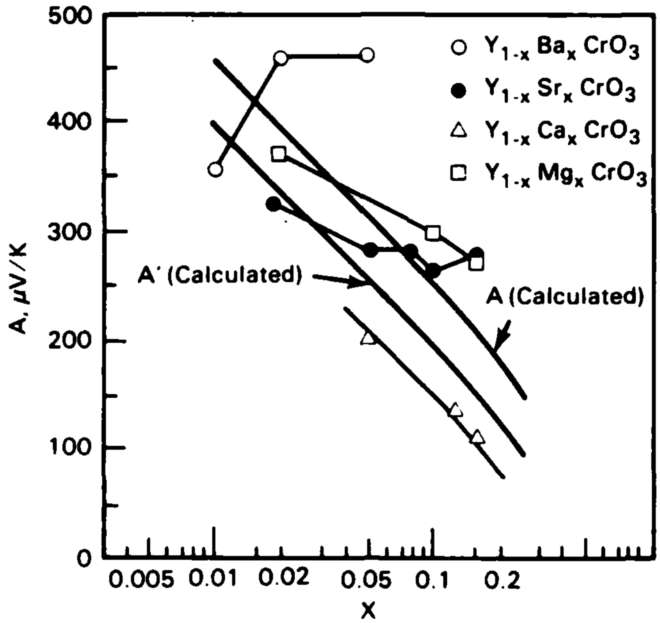

FIGURE 4.6. Experimentally Determined Values for A in $(Y_{1-x}M_x)CrO_3$ and Theoretical Values for both A and A'

The factor of '2' included in the expression for A accounts for spin degeneracy. There is no clear indication in Figure 4.6 that one of these forms, A or A', is preferred. Let us assume that A' is correct. Examination of the experimental results versus x indicates that substitution of Ca seems to result in more than one small polaron per Ca atom; while in the other cases, there seems to be less impurity going into the A-site than intended. The results for Ba substitution do not agree with behavior predicted by the model for small polaron transport and are not understood at this time.

Results for the overlap integral, J, are plotted versus x in Figure 4.7. The finite values of J indicate that hopping between inequivalent sites is occurring in these materials. The most significant effect occurs with Mg, which is consistent with the interpretation that some Mg goes onto the B-site.

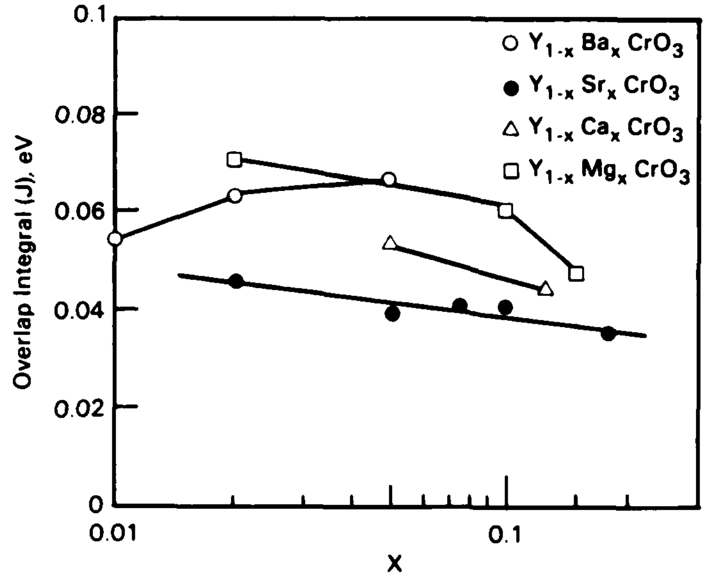

FIGURE 4.7 Experimentally Determined Values of Overlap Integral J in $(Y_xM_x)CrO_3$

Electrical transport properties for these yttrium chromites have been successfully interpreted in terms of small polaron theory. The results suggest some possible approaches for improved (higher) ZT values of the chromites. The addition of small quantities of Mg to the chromites for intended substitution on the A-site results in significant increases of J and, consequently, B. Apparently, a significant fraction of the Mg must substitute for Cr on the B-site. Therefore, improved values of ZT might be achieved by the substitution of Mg for a small fraction of Cr in a highly conducting chromite, such as $Y_{0.9}Ca_{0.1}(Cr_{1-y}Mg_y)O_3$.

5.0 FUTURE DIRECTION

Future research will continue to emphasize the small polaron transport model. To verify and refine the model, experimental transport measurements will investigate the effects of substitution in the ABO_3 perovskite structure, particularly substitution on the B or O sites, which should increase the inequivalent sites for hopping of small polarons.

The recent improvements in the thermal diffusivity apparatus will allow an investigation of the effect of dopant (ionic radius) on thermal conductivity and hence ZT. Lattice distortion, such as that discussed in Section 3.3.2, should decrease thermal transport and increase ZT. These measurements have been initiated for the next reporting period.

Next year, studies will be initiated on other material systems, such as the sulfides and oxysulfides. Sulfides are known to exhibit high electrical conductivity but lower thermal conductivity than the chromites (Taher and Gruber, 1981). Initial work will concentrate on sulfur substitution for oxygen in the ABO_3 perovskites, since this will allow easy application of the model. Some material preparation work has already been initiated. Eventually, other oxysulfides and sulfides will be investigated with compositions based on model predictions.

6.0 REFERENCES

Emin, D. and C. Wood. 1983. "Small-Polaron Electronic Transport in Boron Carbides." Proc. 18th Intersociety Energy Conversion Engineering Conference, P. 222.

Heikes, R. R. and R. W. Ure, Jr. 1961. Thermoelectricity: Science and Engineering. Interscience Publishers, New York.

Laubitz, M. J. 1969. "Transport Properties of Pure Metals at High Temperatures." Can. J. Phys., 47:2633-2644.

Moore, J. P. and R. S. Graves. 1973. "Absolute Seebeck Coefficient from 80 to 340 K and Electrical Conductivity of Lead from 80 to 400 K." J. Appl. Phys. 44:1174-1178.

Pechini, M. 1967. "Methods of Preparing Lead and Alkaline Earth Titanates and Niobates and Coating Methods Using the Same to Form a Capacitor." U.S. Patent #3,330,597.

Schmidt, H. 1981. Electrical Properties of Lanthanum Chromite Based Ceramics in Hydrogen and Oxidizing Atmospheres at High Temperatures. DOE/ET/1541501. Montana State University, Bozeman, Montana.

Taher, S. M. and J. B. Gruber. 1981. "Thermoelectric Efficiency of Rare-Earth Sesquisulfides." Mat. Res. Bull., 16:1407.

Ure, R. W. 1972. "Practical Limits to the Thermoelectric Figure of Merit-II." Energy Conversion, 12:45.

APPENDIX A - THERMOELECTRIC PROPERTY DATA

THERMOELECTRIC PROPERTIES

COMPOSITION: (La0.5,Y0.5)0.98Sr0.02CrO3

SAMPLE #: AF_14

COMMENTS:

PROPERTY	UNITS	COEFFICIENTS A	B	C	D	R^2	TEMPERATURE, K MINIMUM	MAXIMUM
log sigma	1/(ohm-cm)	5.820E-01	3.864E+02	----	----	0.990	567	1544
log(sigmaxK)	K/(ohm-cm)	4.124E+00	7.314E+02	----	----	0.999	567	1544
lambda	W/(m-K)	2.927E-01	2.355E-04	----	----	-----	---	----
S	uV/K	2.105E+02	3.498E-01	-3.400E-04	1.216E-07	0.880	606	1350

CALCULATED THERMOELECTRIC PROPERTIES

	Temperature K	log sigma 1/(ohm-cm)	log(sigmaxK) K/(ohm-cm)	lambda W/cm-K	S uV/K	Z 1/K	ZT
1	500	-1.908E-01	2.661E+00	2.436E-02	3.156E+02	2.634E-06	1.317E-03
2	600	-6.203E-02	2.905E+00	2.304E-02	3.243E+02	3.956E-06	2.373E-03
3	700	2.997E-02	3.079E+00	2.186E-02	3.305E+02	5.354E-06	3.748E-03
4	800	9.898E-02	3.210E+00	2.079E-02	3.350E+02	6.781E-06	5.425E-03
5	900	1.526E-01	3.311E+00	1.992E-02	3.386E+02	8.221E-06	7.399E-03
6	1000	1.956E-01	3.393E+00	1.893E-02	3.419E+02	9.687E-06	9.687E-03
7	1100	2.307E-01	3.459E+00	1.812E-02	3.457E+02	1.122E-05	1.234E-02
8	1200	2.600E-01	3.514E+00	1.738E-02	3.508E+02	1.288E-05	1.546E-02
9	1300	2.848E-01	3.561E+00	1.670E-02	3.578E+02	1.477E-05	1.920E-02
10	1400	3.060E-01	3.602E+00	1.607E-02	3.675E+02	1.700E-05	2.380E-02

NOTES

1) Thermal conductivity data was estimated.

THERMOELECTRIC PROPERTIES

COMPOSITION: (La0.5,Gd0.5)0.98Sr0.02CrO3

SAMPLE #: AF_15

COMMENTS:

PROPERTY	UNITS	COEFFICIENTS A	B	C	D	R^2	TEMPERATURE, K MINIMUM	MAXIMUM
log sigma	1/(ohm-cm)	7.000E-01	3.287E+02	----	----	0.990	585	1543
log(sigmaxK)	K/(ohm-cm)	4.125E+00	7.261E+02	----	----	0.999	524	1441
lambda	W/(m-K)	2.927E-01	2.355E-04	----	----	-----	---	----
S	uV/K	3.040E+02	4.870E-02	-1.124E-05	8.351E-09	0.910	610	1338

CALCULATED THERMOELECTRIC PROPERTIES

	Temperature K	log sigma 1/(ohm-cm)	log(sigmaxK) K/(ohm-cm)	lambda W/cm-K	S uV/K	Z 1/K	ZT
1	500	4.261E-02	2.673E+00	2.436E-02	3.265E+02	4.828E-06	2.414E-03
2	600	1.522E-01	2.915E+00	2.304E-02	3.309E+02	6.747E-06	4.048E-03
3	700	2.304E-01	3.088E+00	2.186E-02	3.354E+02	8.750E-06	6.125E-03
4	800	2.891E-01	3.217E+00	2.079E-02	3.400E+02	1.082E-05	8.657E-03
5	900	3.348E-01	3.318E+00	1.982E-02	3.448E+02	1.297E-05	1.167E-02
6	1000	3.713E-01	3.399E+00	1.893E-02	3.498E+02	1.519E-05	1.519E-02
7	1100	4.012E-01	3.465E+00	1.812E-02	3.550E+02	1.752E-05	1.927E-02
8	1200	4.261E-01	3.520E+00	1.738E-02	3.606E+02	1.996E-05	2.395E-02
9	1300	4.472E-01	3.566E+00	1.670E-02	3.666E+02	2.254E-05	2.930E-02

NOTES

1) Thermal conductivity data was estimated.

THERMOELECTRIC PROPERTIES

COMPOSITION: (Y0.5,Gd0.5)0.98Sr0.02CrO3

SAMPLE #: AF_16

COMMENTS:

PROPERTY	UNITS	COEFFICIENTS A	B	C	D	R^2	TEMPERATURE, K MINIMUM	MAXIMUM
log sigma	1/(ohm-cm)	9.860E-02	9.245E+02	----	----	0.990	552	1549
log(sigmaxK)	K/(ohm-cm)	3.512E+00	1.314E+03	----	----	0.999	552	1549
lambda	W/(m-K)	2.927E-01	2.355E-04	----	----	-----	---	----
S	uV/K	5.571E+02	-1.535E-01	1.940E-04	-6.505E-09	0.590	603	1286

CALCULATED THERMOELECTRIC PROPERTIES

	Temperature K	log sigma 1/(ohm-cm)	log(sigmaxK) K/(ohm-cm)	lambda W/cm-K	S uV/K	Z 1/K	ZT
1	500	-1.750E+00	8.835E-01	2.436E-02	5.280E+02	2.033E-07	1.016E-04
2	600	-1.442E+00	1.322E+00	2.304E-02	5.334E+02	4.460E-07	2.676E-04
3	700	-1.222E+00	1.634E+00	2.186E-02	5.424E+02	8.072E-07	5.650E-04
4	800	-1.057E+00	1.869E+00	2.079E-02	5.551E+02	1.300E-06	1.040E-03
5	900	-9.287E-01	2.052E+00	1.982E-02	5.713E+02	1.941E-06	1.747E-03
6	1000	-8.259E-01	2.198E+00	1.893E-02	5.911E+02	2.755E-06	2.755E-03
7	1100	-7.419E-01	2.317E+00	1.812E-02	6.143E+02	3.772E-06	4.149E-03
8	1200	-6.718E-01	2.417E+00	1.738E-02	6.410E+02	5.032E-06	6.038E-03
9	1300	-6.126E-01	2.501E+00	1.670E-02	6.711E+02	6.581E-06	8.555E-03

NOTES

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1) Thermal conductivity data was estimated.

THERMOELECTRIC PROPERTIES

COMPOSITION: (Y0.99,Ba0.01)CrO3

SAMPLE #: AF_17

COMMENTS:

PROPERTY	UNITS	COEFFICIENTS A	B	C	D	R^2	TEMPERATURE, K MINIMUM	MAXIMUM
log sigma	1/(ohm-cm)	1.500E-01	1.021E+03	----	----	0.990	624	1512
log(sigmaxK)	K/(ohm-cm)	3.575E+00	1.429E+03	----	----	0.990	624	1512
lambda	W/(m-K)	2.927E-01	2.355E-04	----	----	-----	---	----
S	uV/K	1.068E+02	8.027E-01	-7.635E-04	2.501E-07	0.950	784	1312

CALCULATED THERMOELECTRIC PROPERTIES

	Temperature K	log sigma 1/(ohm-cm)	log(sigmaxK) K/(ohm-cm)	lambda W/cm-K	S uV/K	Z 1/K	ZT
1	700	-1.309E+00	1.534E+00	2.186E-02	3.804E+02	3.252E-07	2.276E-04
2	800	-1.126E+00	1.789E+00	2.079E-02	3.884E+02	5.425E-07	4.340E-04
3	900	-9.846E-01	1.987E+00	1.982E-02	3.931E+02	8.082E-07	7.273E-04
4	1000	-8.711E-01	2.146E+00	1.893E-02	3.961E+02	1.115E-06	1.115E-03
5	1100	-7.783E-01	2.276E+00	1.812E-02	3.989E+02	1.462E-06	1.609E-03
6	1200	-7.009E-01	2.384E+00	1.738E-02	4.028E+02	1.858E-06	2.230E-03
7	1300	-6.355E-01	2.476E+00	1.670E-02	4.095E+02	2.324E-06	3.022E-03

NOTES
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1) Thermal conductivity data was estimated.

THERMOELECTRIC PROPERTIES

COMPOSITION: (Y0.98,Ba0.02)CrO3

SAMPLE #: AF_18

COMMENTS:

PROPERTY	UNITS	COEFFICIENTS A	B	C	D	R^2	TEMPERATURE, K MINIMUM	MAXIMUM
log sigma	1/(ohm-cm)	1.500E-01	8.930E+02	----	----	0.990	569	1552
log(sigmaxK)	K/(ohm-cm)	3.570E+00	1.290E+03	----	----	0.999	569	1552
lambda	W/(m-K)	2.927E-01	2.355E-04	----	----	-----	---	----
S	uV/K	2.824E+02	6.152E-01	-5.971E-04	2.020E-07	0.690	590	1320

CALCULATED THERMOELECTRIC PROPERTIES

	Temperature K	log sigma 1/(ohm-cm)	log(sigmaxK) K/(ohm-cm)	lambda W/cm-K	S uV/K	Z 1/K	ZT
1	500	-1.636E+00	9.891E-01	2.436E-02	4.660E+02	2.060E-07	1.030E-04
2	600	-1.338E+00	1.419E+00	2.304E-02	4.802E+02	4.591E-07	2.755E-04
3	700	-1.126E+00	1.727E+00	2.186E-02	4.897E+02	8.214E-07	5.750E-04
4	800	-9.663E-01	1.957E+00	2.079E-02	4.958E+02	1.278E-06	1.023E-03
5	900	-8.423E-01	2.136E+00	1.982E-02	4.997E+02	1.812E-06	1.631E-03
6	1000	-7.430E-01	2.280E+00	1.893E-02	5.025E+02	2.410E-06	2.410E-03
7	1100	-6.618E-01	2.397E+00	1.812E-02	5.055E+02	3.071E-06	3.378E-03
8	1200	-5.942E-01	2.495E+00	1.738E-02	5.099E+02	3.807E-06	4.568E-03
9	1300	-5.369E-01	2.577E+00	1.670E-02	5.168E+02	4.646E-06	6.040E-03

NOTES

1) Thermal conductivity data was estimated.

THERMOELECTRIC PROPERTIES

COMPOSITION: (Y0.95,Ba0.05)CrO3

SAMPLE #: AF_19

COMMENTS:

PROPERTY	UNITS	COEFFICIENTS A	B	C	D	R^2	TEMPERATURE, K MINIMUM	MAXIMUM
log sigma	1/(ohm-cm)	2.800E-01	8.747E+02	----	----	0.990	571	1556
log(sigmaxK)	K/(ohm-cm)	3.701E+00	1.273E+03	----	----	0.999	571	1556
lambda	W/(m-K)	2.927E-01	2.355E-04	----	----	-----	---	----
S	uV/K	4.752E+02	-8.100E-03	7.392E-05	-2.958E-08	0.760	601	1333

CALCULATED THERMOELECTRIC PROPERTIES

	Temperature K	log sigma 1/(ohm-cm)	log(sigmaxK) K/(ohm-cm)	lambda W/cm-K	S uV/K	Z 1/K	ZT
1	500	-1.469E+00	1.154E+00	2.436E-02	4.859E+02	3.288E-07	1.644E-04
2	600	-1.178E+00	1.579E+00	2.304E-02	4.906E+02	6.934E-07	4.161E-04
3	700	-9.696E-01	1.882E+00	2.186E-02	4.956E+02	1.205E-06	8.437E-04
4	800	-8.134E-01	2.109E+00	2.079E-02	5.009E+02	1.855E-06	1.484E-03
5	900	-6.919E-01	2.286E+00	1.982E-02	5.062E+02	2.629E-06	2.366E-03
6	1000	-5.947E-01	2.428E+00	1.893E-02	5.114E+02	3.513E-06	3.513E-03
7	1100	-5.152E-01	2.543E+00	1.812E-02	5.164E+02	4.492E-06	4.941E-03
8	1200	-4.489E-01	2.640E+00	1.738E-02	5.208E+02	5.550E-06	6.660E-03
9	1300	-3.929E-01	2.722E+00	1.670E-02	5.246E+02	6.670E-06	8.671E-03

NOTES

1) Thermal conductivity data was estimated.

THERMOELECTRIC PROPERTIES

COMPOSITION: (Y0.98,Sr0.02)CrO3

SAMPLE #: AF_20

COMMENTS:

PROPERTY	UNITS	COEFFICIENTS A	B	C	D	R^2	TEMPERATURE, K MINIMUM	MAXIMUM
log sigma	1/(ohm-cm)	8.870E-01	7.964E+02	----	----	0.990	468	1517
log(sigmaxK)	K/(ohm-cm)	4.269E+00	1.149E+03	----	----	0.990	468	1517
lambda	W/(m-K)	1.355E-01	3.119E-04	----	----	-----	---	----
S	uV/K	2.795E+02	2.150E-01	-2.067E-04	7.689E-08	0.830	627	1518

CALCULATED THERMOELECTRIC PROPERTIES

	Temperature K	log sigma 1/(ohm-cm)	log(sigmaxK) K/(ohm-cm)	lambda W/cm-K	S uV/K	Z 1/K	ZT
1	500	-7.059E-01	1.971E+00	3.431E-02	3.449E+02	6.825E-07	3.412E-04
2	600	[illegible]404E-01	2.354E+00	3.099E-02	3.507E+02	1.439E-06	8.635E-04
3	700	-2.508E-01	2.628E+00	2.826E-02	3.550E+02	2.504E-06	1.753E-03
4	800	-1.085E-01	2.833E+00	2.597E-02	3.585E+02	3.855E-06	3.084E-03
5	900	2.078E-03	2.992E+00	2.403E-02	3.616E+02	5.468E-06	4.921E-03
6	1000	9.057E-02	3.120E+00	2.235E-02	3.646E+02	7.328E-06	7.328E-03
7	1100	1.630E-01	3.224E+00	2.089E-02	3.682E+02	9.442E-06	1.039E-02
8	1200	2.233E-01	3.312E+00	1.962E-02	3.727E+02	1.184E-05	1.421E-02
9	1300	2.744E-01	3.385E+00	1.849E-02	3.786E+02	1.458E-05	1.896E-02
10	1400	3.181E-01	3.448E+00	1.748E-02	3.863E+02	1.776E-05	2.487E-02

NOTES

1) Thermal conductivity data was estimated.

THERMOELECTRIC PROPERTIES

COMPOSITION: (Y0.95,Sr0.05)CrO3

SAMPLE #: AF_21

COMMENTS:

PROPERTY	UNITS	COEFFICIENTS A	B	C	D	R²	TEMPERATURE, K MINIMUM	MAXIMUM
log sigma	1/(ohm-cm)	6.300E-01	5.300E+02	----	----	0.990	521	1557
log(sigmaxK)	K/(ohm-cm)	4.033E+00	9.067E+02	----	----	0.990	521	1557
lambda	W/(m-K)	2.348E-01	2.827E-04	----	----	0.994	517	1411
S	uV/K	3.412E+02	-1.310E-01	1.790E-04	-5.824E-08	0.860	617	1389

CALCULATED THERMOELECTRIC PROPERTIES

	Temperature K	log sigma 1/(ohm-cm)	log(sigmaxK) K/(ohm-cm)	lambda W/cm-K	S uV/K	Z 1/K	ZT
1	500	-4.300E-01	2.220E+00	2.659E-02	3.131E+02	1.370E-06	6.852E-04
2	600	-2.533E-01	2.522E+00	2.473E-02	3.144E+02	2.231E-06	1.339E-03
3	700	-1.271E-01	2.738E+00	2.311E-02	3.172E+02	3.249E-06	2.274E-03
4	800	-3.249E-02	2.900E+00	2.170E-02	3.211E+02	4.410E-06	3.528E-03
5	900	4.112E-02	3.026E+00	2.044E-02	3.258E+02	5.708E-06	5.138E-03
6	1000	1.000E-01	3.126E+00	1.933E-02	3.309E+02	7.135E-06	7.135E-03
7	1100	1.482E-01	3.209E+00	1.832E-02	3.361E+02	8.674E-06	9.541E-03
8	1200	1.883E-01	3.277E+00	1.742E-02	3.411E+02	1.030E-05	1.236E-02
9	1300	2.223E-01	3.336E+00	1.660E-02	3.454E+02	1.199E-05	1.559E-02
10	1400	2.514E-01	3.385E+00	1.586E-02	3.488E+02	1.369E-05	1.916E-02

THERMOELECTRIC PROPERTIES

COMPOSITION: (Y0.925Sr0.075)CrO3

SAMPLE #: AF_22

COMMENTS:

PROPERTY	UNITS	A	B	C	D	R²	TEMPERATURE, K MINIMUM	MAXIMUM
log sigma	1/(ohm-cm)	7.250E-01	5.236E+02	----	----	0.990	608	1556
log(sigmaxK)	K/(ohm-cm)	4.165E+00	9.408E+02	----	----	0.990	608	1556
lambda	W/(m-K)	1.355E-01	3.119E-04	----	----	-----	---	----
S	uV/K	3.721E+02	-2.090E-01	2.329E-04	-6.951E-08	0.880	757	1475

CALCULATED THERMOELECTRIC PROPERTIES

	Temperature K	log sigma 1/(ohm-cm)	log(sigmaxK) K/(ohm-cm)	lambda W/cm-K	S uV/K	Z 1/K	ZT
1	700	-2.299E-02	2.821E+00	2.826E-02	3.161E+02	3.352E-06	2.347E-03
2	800	7.051E-02	2.989E+00	2.597E-02	3.184E+02	4.590E-06	3.672E-03
3	900	1.432E-01	3.120E+00	2.403E-02	3.220E+02	6.000E-06	5.400E-03
4	1000	2.014E-01	3.224E+00	2.235E-02	3.265E+02	7.582E-06	7.582E-03
5	1100	2.490E-01	3.310E+00	2.089E-02	3.315E+02	9.330E-06	1.026E-02
6	1200	2.887E-01	3.381E+00	1.962E-02	3.365E+02	1.122E-05	1.347E-02
7	1300	3.222E-01	3.441E+00	1.849E-02	3.413E+02	1.323E-05	1.720E-02
8	1400	3.510E-01	3.493E+00	1.748E-02	3.452E+02	1.530E-05	2.142E-02
9	1500	3.759E-01	3.538E+00	1.657E-02	3.480E+02	1.737E-05	2.605E-02

NOTES

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1) Thermal conductivity data was estimated.

THERMOELECTRIC PROPERTIES

COMPOSITION: (Y0.90Sr0.10)CrO3

SAMPLE #: AF_23

COMMENTS:

PROPERTY	UNITS	COEFFICIENTS A	B	C	D	R^2	TEMPERATURE, K MINIMUM	MAXIMUM
log sigma	1/(ohm-cm)	7.650E-01	4.938E+02	----	----	0.990	663	1523
log(sigmaxK)	K/(ohm-cm)	4.203E+00	9.157E+02	----	----	0.990	663	1523
lambda	W/(m-K)	1.355E-01	3.119E-04	----	----	0.990	500	1550
S	uV/K	2.191E+02	1.580E-01	-9.842E-05	3.104E-08	0.920	607	1474

CALCULATED THERMOELECTRIC PROPERTIES

	Temperature K	log sigma 1/(ohm-cm)	log(sigmaxK) K/(ohm-cm)	lambda W/cm-K	S uV/K	Z 1/K	ZT
1	600	-5.803E-02	2.677E+00	3.099E-02	2.852E+02	2.296E-06	1.378E-03
2	700	5.955E-02	2.895E+00	2.826E-02	2.921E+02	3.464E-06	2.425E-03
3	800	1.477E-01	3.058E+00	2.597E-02	2.984E+02	4.818E-06	3.855E-03
4	900	2.163E-01	3.186E+00	2.403E-02	3.042E+02	6.339E-06	5.705E-03
5	1000	2.712E-01	3.287E+00	2.235E-02	3.097E+02	8.015E-06	8.015E-03
6	1100	3.161E-01	3.371E+00	2.089E-02	3.152E+02	9.842E-06	1.083E-02
7	1200	3.535E-01	3.440E+00	1.962E-02	3.206E+02	1.183E-05	1.419E-02
8	1300	3.851E-01	3.499E+00	1.849E-02	3.264E+02	1.399E-05	1.819E-02
9	1400	4.123E-01	3.549E+00	1.748E-02	3.326E+02	1.635E-05	2.290E-02
10	1500	4.358E-01	3.593E+00	1.657E-02	3.394E+02	1.896E-05	2.844E-02

THERMOELECTRIC PROPERTIES

COMPOSITION: (Y0.85,Sr0.15)CrO3

SAMPLE #: AF_24

COMMENTS:

PROPERTY	UNITS	COEFFICIENTS A	B	C	D	R^2	TEMPERATURE, K MINIMUM	MAXIMUM
log sigma	1/(ohm-cm)	8.010E-01	5.656E+02	----	----	0.990	647	1521
log(sigmaxK)	K/(ohm-cm)	4.235E+00	9.829E+02	----	----	0.990	647	1521
lambda	W/(m-K)	1.355E-01	3.119E-04	----	----	-----	---	----
S	uV/K	4.497E+02	-5.740E-01	6.790E-04	-2.409E-07	0.870	604	1411

CALCULATED THERMOELECTRIC PROPERTIES

	Temperature K	log sigma 1/(ohm-cm)	log(sigmaxK) K/(ohm-cm)	lambda W/cm-K	S uV/K	Z 1/K	ZT
1	500	-3.302E-01	2.269E+00	3.431E-02	3.024E+02	1.246E-06	6.229E-04
2	600	-1.417E-01	2.597E+00	3.099E-02	2.978E+02	2.064E-06	1.238E-03
3	700	-7.034E-03	2.831E+00	2.826E-02	2.980E+02	3.092E-06	2.165E-03
4	800	9.397E-02	3.006E+00	2.597E-02	3.018E+02	4.353E-06	3.482E-03
5	900	1.725E-01	3.143E+00	2.403E-02	3.075E+02	5.856E-06	5.270E-03
6	1000	2.354E-01	3.252E+00	2.235E-02	3.138E+02	7.577E-06	7.577E-03
7	1100	2.868E-01	3.341E+00	2.089E-02	3.193E+02	9.444E-06	1.039E-02
8	1200	3.296E-01	3.416E+00	1.962E-02	3.224E+02	1.132E-05	1.359E-02
9	1300	3.659E-01	3.479E+00	1.849E-02	3.218E+02	1.301E-05	1.691E-02

NOTES

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1) Thermal conductivity data was estimated.

THERMOELECTRIC PROPERTIES

COMPOSITION: (Y0.95,Ca0.05)CrO3

SAMPLE #: AF_25

COMMENTS:

PROPERTY	UNITS	COEFFICIENTS A	B	C	D	R²	TEMPERATURE, K MINIMUM	MAXIMUM
log sigma	1/(ohm-cm)	1.376E+00	7.582E+02	----	----	0.996	657	992
		9.820E-01	3.696E+02	----	----	0.989	992	1543
log(sigmaxK)	K/(ohm-cm)	4.720E+00	1.106E+03	----	----	0.999	657	992
		4.506E+00	8.984E+02	----	----	0.999	992	1543
lambda	W/(m-K)	2.927E-01	2.355E-04	----	----	-----	---	----
S	uV/K	1.687E+02	2.184E-01	-2.137E-04	8.457E-08	0.955	564	1504

CALCULATED THERMOELECTRIC PROPERTIES

	Temperature K	log sigma 1/(ohm-cm)	log(sigmaxK) K/(ohm-cm)	lambda W/cm-K	S uV/K	Z 1/K	ZT
1	600	1.123E-01	2.877E+00	2.304E-02	2.411E+02	3.266E-06	1.960E-03
2	700	2.928E-01	3.140E+00	2.186E-02	2.459E+02	5.428E-06	3.799E-03
3	800	4.282E-01	3.338E+00	2.079E-02	2.499E+02	8.056E-06	6.444E-03
4	900	5.714E-01	3.508E+00	1.982E-02	2.538E+02	1.211E-05	1.090E-02
5	1000	6.124E-01	3.608E+00	1.893E-02	2.580E+02	1.440E-05	1.440E-02
6	1100	6.460E-01	3.689E+00	1.812E-02	2.629E+02	1.688E-05	1.857E-02
7	1200	6.740E-01	3.757E+00	1.738E-02	2.692E+02	1.968E-05	2.361E-02
8	1300	6.977E-01	3.815E+00	1.670E-02	2.772E+02	2.295E-05	2.983E-02
9	1400	7.180E-01	3.864E+00	1.607E-02	2.877E+02	2.690E-05	3.766E-02
10	1500	7.356E-01	3.907E+00	1.548E-02	3.009E+02	3.181E-05	4.772E-02

NOTES
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1) Thermal conductivity data was estimated.

THERMOELECTRIC PROPERTIES

COMPOSITION: (Y0.875,Ca0.125)CrO3

SAMPLE #: AF_26

COMMENTS:

PROPERTY	UNITS	COEFFICIENTS A	B	C	D	R^2	TEMPERATURE, K MINIMUM	MAXIMUM
log sigma	1/(ohm-cm)	1.580E+00	6.838E+02	----	----	0.984	643	1179
		1.199E+00	2.331E+02	----	----	0.862	1179	1520
log(sigmaxK)	K/(ohm-cm)	4.956E+00	1.055E+03	----	----	0.992	643	1179
		4.760E+00	8.123E+02	----	----	0.992	1179	1520
lambda	W/(m-K)	4.219E-01	2.120E-04	----	----	0.976	647	1407
S	uV/K	8.480E+01	2.107E-01	-1.648E-04	5.368E-08	0.990	602	1341

CALCULATED THERMOELECTRIC PROPERTIES

	Temperature F	log sigma 1/(ohm-cm)	log(sigmaxK) K/(ohm-cm)	lambda W/cm-K	S uV/K	Z 1/K	ZT
1	500	2.124E-01	2.846E+00	1.894E-02	1.557E+02	2.086E-06	1.043E-03
2	600	4.403E-01	3.198E+00	1.821E-02	1.635E+02	4.045E-06	2.427E-03
3	700	6.031E-01	3.449E+00	1.754E-02	1.699E+02	6.605E-06	4.623E-03
4	800	7.253E-01	3.637E+00	1.691E-02	1.754E+02	9.663E-06	7.730E-03
5	900	8.202E-01	3.784E+00	1.632E-02	1.801E+02	1.313E-05	1.182E-02
6	1000	8.962E-01	3.901E+00	1.578E-02	1.844E+02	1.697E-05	1.697E-02
7	1100	9.871E-01	4.022E+00	1.527E-02	1.886E+02	2.262E-05	2.488E-02
8	1200	1.005E+00	4.083E+00	1.479E-02	1.931E+02	2.549E-05	3.059E-02
9	1300	1.029E+00	4.135E+00	1.434E-02	1.981E+02	2.365E-05	3.724E-02

THERMOELECTRIC PROPERTIES

COMPOSITION: (Y0.85,Ca0.15)CrO3

SAMPLE #: AF_27

COMMENTS:

PROPERTY	UNITS	COEFFICIENTS A	B	C	D	R^2	TEMPERATURE, K MINIMUM	MAXIMUM
log sigma	1/(ohm-cm)	1.401E+00	4.605E+02	----	----	0.999	736	1183
		1.258E+00	2.914E+02	----	----	0.997	1183	1550
log(sigmaxK)	K/(ohm-cm)	4.768E+00	8.221E+02	----	----	0.999	557	1183
		4.815E+00	8.653E+02	----	----	0.999	1183	1550
lambda	W/(m-K)	1.693E-01	8.576E-04	----	----	0.904	543	1401
S	uV/K	7.894E+01	1.439E-01	-8.630E-05	2.636E-08	0.986	626	1458

CALCULATED THERMOELECTRIC PROPERTIES

	Temperature K	log sigma 1/(ohm-cm)	log(sigmaxK) K/(ohm-cm)	lambda W/cm-K	S uV/K	Z 1/K	ZT
1	600	6.335E-01	3.398E+00	1.462E-02	1.399E+02	5.757E-06	3.454E-03
2	700	7.432E-01	3.594E+00	1.299E-02	1.464E+02	9.135E-06	6.394E-03
3	800	8.254E-01	3.740E+00	1.169E-02	1.523E+02	1.328E-05	1.062E-02
4	900	8.893E-01	3.855E+00	1.062E-02	1.578E+02	1.816E-05	1.634E-02
5	1000	9.405E-01	3.946E+00	9.738E-03	1.629E+02	2.376E-05	2.376E-02
6	1100	9.931E-01	4.028E+00	8.987E-03	1.679E+02	3.087E-05	3.396E-02
7	1200	1.015E+00	4.094E+00	8.344E-03	1.729E+02	3.710E-05	4.452E-02
8	1300	1.034E+00	4.149E+00	7.787E-03	1.781E+02	4.403E-05	5.724E-02
9	1400	1.050E+00	4.197E+00	7.299E-03	1.836E+02	5.179E-05	7.251E-02

THERMOELECTRIC PROPERTIES

COMPOSITION: (Y0.98,Mg0.02)CrO3

SAMPLE #: AF_28

COMMENTS:

PROPERTY	UNITS	COEFFICIENTS A	B	C	D	R^2	TEMPERATURE, K MINIMUM	MAXIMUM
log sigma	1/(ohm-cm)	7.400E-01	9.516E+02	----	----	0.996	607	875
		3.500E-01	6.046E+02	----	----	0.999	875	1547
log(sigmaxK)	K/(ohm-cm)	4.037E+00	1.264E+03	----	----	0.997	607	875
		3.857E+00	1.108E+03	----	----	0.998	875	1547
lambda	W/(m-K)	2.927E-01	2.355E-04	----	----	-----	---	----
S	uV/K	4.925E+02	-1.900E-01	1.555E-04	-2.374E-08	0.972	749	1516

CALCULATED THERMOELECTRIC PROPERTIES

	Temperature K	log sigma 1/(ohm-cm)	log(sigmaxK) K/(ohm-cm)	lambda W/cm-K	S uV/K	Z 1/K	ZT
1	600	-8.459E-01	1.930E+00	2.304E-02	4.293E+02	1.140E-06	6.843E-04
2	700	-6.194E-01	2.231E+00	2.186E-02	4.275E+02	2.009E-06	1.406E-03
3	800	-4.057E-01	2.472E+00	2.079E-02	4.278E+02	3.460E-06	2.768E-03
4	900	-3.217E-01	2.626E+00	1.982E-02	4.301E+02	4.450E-06	4.005E-03
5	1000	-2.546E-01	2.749E+00	1.893E-02	4.342E+02	5.541E-06	5.541E-03
6	1100	-1.996E-01	2.850E+00	1.812E-02	4.400E+02	6.746E-06	7.421E-03
7	1200	-1.538E-01	2.934E+00	1.738E-02	4.474E+02	8.079E-06	9.695E-03
8	1300	-1.151E-01	3.005E+00	1.670E-02	4.561E+02	9.558E-06	1.243E-02
9	1400	-8.184E-02	3.066E+00	1.607E-02	4.661E+02	1.120E-05	1.568E-02
10	1500	-5.305E-02	3.118E+00	1.548E-02	4.772E+02	1.302E-05	1.953E-02

NOTES
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1) Thermal conductivity data was estimated.

THERMOELECTRIC PROPERTIES

COMPOSITION: (Y0.90,Mg0.10)CrO3

SAMPLE #: AF_29

COMMENTS:

PROPERTY	UNITS	COEFFICIENTS A	B	C	D	R^2	TEMPERATURE, K MINIMUM	MAXIMUM
log sigma	1/(ohm-cm)	9.670E-01	8.977E+02	----	----	0.992	609	987
		5.400E-01	4.913E+02	----	----	0.997	987	1549
log(sigmaxK)	K/(ohm-cm)	4.291E+00	1.229E+03	----	----	0.998	609	987
		4.064E+00	1.019E+03	----	----	0.999	987	1549
lambda	W/(m-K)	2.927E-01	2.355E 04	----	----	-----	---	----
S	uV/K	2.980E+02	1.910E-01	-2.203E-04	8.953E-08	0.825	618	1477

CALCULATED THERMOELECTRIC PROPERTIES

	Temperature K	log sigma 1/(ohm-cm)	log(sigmaxK) K/(ohm-cm)	lambda W/cm-K	S uV/K	Z 1/K	ZT
1	500	-8.283E-01	1.834E+00	2.436E-02	3.497E+02	7.451E-07	3.725E-04
2	600	-5.291E-01	2.243E+00	2.304E-02	3.527E+02	1.596E-06	9.577E-04
3	700	-3.154E-01	2.536E+00	2.186E-02	3.545E+02	2.781E-06	1.947E-03
4	800	-1.551E-01	2.755E+00	2.079E-02	3.557E+02	4.259E-06	3.407E-03
5	900	-5.884E-03	2.931E+00	1.982E-02	3.568E+02	6.336E-06	5.703E-03
6	1000	4.870E-02	3.045E+00	1.893E-02	3.583E+02	7.584E-06	7.584E-03
7	1100	9.337E-02	3.137E+00	1.812E-02	3.607E+02	8.902E-06	9.792E-03
8	1200	1.306E-01	3.215E+00	1.738E-02	3.647E+02	1.034E-05	1.240E-02
9	1300	1.621E-01	3.280E+00	1.670E-02	3.707E+02	1.195E-05	1.554E-02
10	1400	1.891E-01	3.336E+00	1.607E-02	3.793E+02	1.384E-05	1.938E-02

NOTES
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1) *Thermal conductivity data was estimated.*

THERMOELECTRIC PROPERTIES

COMPOSITION: (Y0.85,Mg0.15)CrO3

SAMPLE #: AF_30

COMMENTS:

PROPERTY	UNITS	COEFFICIENTS A	B	C	D	R^2	TEMPERATURE, K MINIMUM	MAXIMUM
log sigma	1/(ohm-cm)	1.190E+00	1.030E+03	----	----	0.998	618	1089
		6.840E-01	4.936E+02	----	----	0.995	1089	1520
log(sigmaxK)	K/(ohm-cm)	4.539E+00	1.380E+03	----	----	0.999	618	1089
		4.228E+00	1.049E+03	----	----	0.999	1089	1520
lambda	W/(m-K)	2.927E-01	2.355E-04	----	----	-----	---	----
S	uV/K	3.562E+02	-1.750E-01	1.450E-04	-2.968E-08	0.380	600	1461

CALCULATED THERMOELECTRIC PROPERTIES

	Temperature K	log sigma 1/(ohm-cm)	log(sigmaxK) K/(ohm-cm)	lambda W/cm-K	S uV/K	Z 1/K	ZT
1	500	-8.708E-01	1.779E+00	2.436E-02	3.013E+02	5.017E-07	2.508E-04
2	600	-5.273E-01	2.239E+00	2.304E-02	2.970E+02	1.137E-06	6.822E-04
3	700	-2.820E-01	2.567E+00	2.186E-02	2.946E+02	2.075E-06	1.452E-03
4	800	-9.799E-02	2.814E+00	2.079E-02	2.938E+02	3.315E-06	2.652E-03
5	900	4.512E-02	3.005E+00	1.982E-02	2.946E+02	4.858E-06	4.372E-03
6	1000	1.904E-01	3.179E+00	1.893E-02	2.966E+02	7.202E-06	7.202E-03
7	1100	2.353E-01	3.275E+00	1.812E-02	2.997E+02	8.519E-06	9.371E-03
8	1200	2.727E-01	3.354E+00	1.738E-02	3.038E+02	9.946E-06	1.193E-02
9	1300	3.043E-01	3.421E+00	1.670E-02	3.086E+02	1.149E-05	1.494E-02
10	1400	3.315E-01	3.479E+00	1.607E-02	3.140E+02	1.316E-05	1.843E-02
11	1500	3.550E-01	3.529E+00	1.548E-02	3.198E+02	1.496E-05	2.244E-02

NOTES
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1) Thermal conductivity data was estimated.

THERMOELECTRIC PROPERTIES

COMPOSITION: (La0.84,Sr0.16)CrO3

SAMPLE #: AF_36

COMMENTS: mgf. by General Refractories

PROPERTY	UNITS	COEFFICIENTS A	B	C	D	R^2	TEMPERATURE, K MINIMUM	MAXIMUM
log sigma	1/(ohm-cm)	1.067E+00	1.321E+03	----	----	0.999	651	1173
		1.994E+00	2.419E+03	----	----	0.996	1173	1548
log(sigmaxK)	K/(ohm-cm)	4.508E+00	1.744E+03	----	----	0.994	651	1548
lambda	W/(m-K)	2.927E-01	2.355E-04	----	----	-----	---	----
S	uV/K	1.772E+02	4.000E-03	-3.984E-06	9.900E-09	0.943	606	1449

CALCULATED THERMOELECTRIC PROPERTIES

	Temperature K	log sigma 1/(ohm-cm)	log(sigmaxK) K/(ohm-cm)	lambda W/cm-K	S uV/K	Z 1/K	ZT
1	600	-1.135E+00	1.601E+00	2.304E-02	1.803E+02	1.033E-07	6.196E-05
2	700	-8.208E-01	2.016E+00	2.186E-02	1.814E+02	2.275E-07	1.593E-04
3	800	-5.849E-01	2.328E+00	2.079E-02	1.829E+02	4.186E-07	3.349E-04
4	900	-4.013E-01	2.570E+00	1.982E-02	1.848E+02	6.839E-07	6.155E-04
5	1000	-2.545E-01	2.764E+00	1.893E-02	1.871E+02	1.029E-06	1.029E-03
6	1100	-2.054E-01	2.922E+00	1.812E-02	1.899E+02	1.241E-06	1.365E-03
7	1200	-2.209E-02	3.055E+00	1.738E-02	1.934E+02	2.044E-06	2.453E-03
8	1300	1.330E-01	3.166E+00	1.670E-02	1.974E+02	3.170E-06	4.121E-03

NOTES

1) Thermal conductivity data was estimated.

THERMOELECTRIC PROPERTIES

COMPOSITION: (La0.84,Sr0.16)(Al0.15,Cr0.85)O3

SAMPLE #: AF_38

COMMENTS: mfg. by General Refractories

PROPERTY	UNITS	COEFFICIENTS A	B	C	D	R^2	TEMPERATURE, K MINIMUM	MAXIMUM
log sigma	1/(ohm-cm)	1.020E+00	1.212E+03	----	----	0.996	637	1280
		2.644E+00	3.264E+03	----	----	0.972	1280	1515
log(sigmaxK)	K/(ohm-cm)	4.411E+00	1.595E+03	----	----	0.995	637	1515
lambda	W/(m-K)	2.927E-01	2.355E-04	----	----	-----	---	----
S	uV/K	1.284E+02	1.120E-01	-1.207E-04	5.454E-08	0.977	612	1459

CALCULATED THERMOELECTRIC PROPERTIES

	Temperature K	log sigma 1/(ohm-cm)	log(sigmaxK) K/(ohm-cm)	lambda W/cm-K	S uV/K	Z 1/K	ZT
1	500	-1.404E+00	1.222E+00	2.436E-02	1.611E+02	4.196E-08	2.098E-05
2	600	-1.000E+00	1.753E+00	2.304E-02	1.639E+02	1.166E-07	6.994E-05
3	700	-7.117E-01	2.133E+00	2.186E-02	1.664E+02	2.460E-07	1.722E-04
4	800	-4.952E-01	2.418E+00	2.079E-02	1.687E+02	4.377E-07	3.502E-04
5	900	-3.269E-01	2.639E+00	1.982E-02	1.712E+02	6.969E-07	6.272E-04
6	1000	-1.922E-01	2.816E+00	1.893E-02	1.743E+02	1.030E-06	1.030E-03
7	1100	-8.198E-02	2.961E+00	1.812E-02	1.782E+02	1.450E-06	1.595E-03
8	1200	-7.623E-02	3.082E+00	1.738E-02	1.832E+02	1.621E-06	1.945E-03
9	1300	1.330E-01	3.184E+00	1.670E-02	1.899E+02	2.932E-06	3.812E-03
10	1400	3.124E-01	3.272E+00	1.607E-02	1.983E+02	5.024E-06	7.034E-03

NOTES
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1) Thermal conductivity data was estimated.

THERMOELECTRIC PROPERTIES

COMPOSITION: (La0.9,Ca0.1)(Al0.15,Cr0.85)O3

SAMPLE #: AF_39

COMMENTS: mfg. by A-T Research

PROPERTY	UNITS	COEFFICIENTS A	B	C	D	R^2	TEMPERATURE, K MINIMUM	MAXIMUM
log sigma	1/(ohm-cm)	1.376E+00	2.473E+02	----	----	0.993	666	1094
		1.222E+00	8.217E+01	----	----	0.917	1094	1517
log(sigmaxK)	K/(ohm-cm)	4.753E+00	6.211E+02	----	----	0.999	666	1517
lambda	W/(m-K)	2.927E-01	2.355E-04	----	----	-----	---	----
S	uV/K	1.282E+02	2.200E-01	-2.304E-04	8.783E-08	0.900	641	1421

CALCULATED THERMOELECTRIC PROPERTIES

	Temperature K	log sigma 1/(ohm-cm)	log(sigmaxK) K/(ohm-cm)	lambda W/cm-K	S uV/K	Z 1/K	ZT
1	600	9.639E-01	3.718E+00	2.304E-02	1.962E+02	1.537E-05	9.224E-03
2	700	1.023E+00	3.866E+00	2.186E-02	1.994E+02	1.917E-05	1.342E-02
3	800	1.067E+00	3.977E+00	2.079E-02	2.017E+02	2.283E-05	1.826E-02
4	900	1.101E+00	4.063E+00	1.982E-02	2.036E+02	2.641E-05	2.376E-02
5	1000	1.140E+00	4.132E+00	1.893E-02	2.056E+02	3.081E-05	3.081E-02
6	1100	1.147E+00	4.188E+00	1.812E-02	2.083E+02	3.360E-05	3.696E-02
7	1200	1.154E+00	4.235E+00	1.738E-02	2.122E+02	3.688E-05	4.425E-02
8	1300	1.159E+00	4.275E+00	1.670E-02	2.178E+02	4.093E-05	5.321E-02

NOTES

1) Thermal conductivity data was estimated.

THERMOELECTRIC PROPERTIES

COMPOSITION: La(Mg0.02,Al0.15,Cr0.83)O3

SAMPLE #: AF_40

COMMENTS: mfg. by General Refractories

PROPERTY	UNITS	COEFFICIENTS A	B	C	D	R^2	TEMPERATURE, K MINIMUM	MAXIMUM
log sigma	1/(ohm-cm)	4.110E-01	4.080E+02	----	----	0.997	661	1092
		2.640E-01	2.506E+02	----	----	0.987	1092	1521
log(sigmaxK)	K/(ohm-cm)	3.791E+00	7.840E+02	----	----	0.999	661	1521
lambda	W/(m-K)	2.927E-01	2.355E-04	----	----	-----	---	----
S	uV/K	8.501E+01	1.274E+00	-1.655E-03	6.442E-07	0.681	601	1437

CALCULATED THERMOELECTRIC PROPERTIES

	Temperature K	log sigma 1/(ohm-cm)	log(sigmaxK) K/(ohm-cm)	lambda W/cm-K	S uV/K	Z 1/K	ZT
1	600	-2.690E-01	2.484E+00	2.304E-02	3.928E+02	3.603E-06	2.162E-03
2	700	-1.719E-01	2.671E+00	2.186E-02	3.868E+02	4.609E-06	3.226E-03
3	800	-9.901E-02	2.811E+00	2.079E-02	3.748E+02	5.382E-06	4.305E-03
4	900	-4.234E-02	2.920E+00	1.982E-02	3.607E+02	5.955E-06	5.360E-03
5	1000	1.343E-02	3.007E+00	1.893E-02	3.482E+02	6.606E-06	6.606E-03
6	1100	3.621E-02	3.078E+00	1.812E-02	3.413E+02	6.985E-06	7.684E-03
7	1200	5.519E-02	3.138E+00	1.738E-02	3.438E+02	7.721E-06	9.265E-03
8	1300	7.126E-02	3.188E+00	1.670E-02	3.596E+02	9.123E-06	1.186E-02

NOTES

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1) Thermal conductivity data was estimated.

THERMOELECTRIC PROPERTIES

COMPOSITION: La(Mg0.02,Al0.15,Cr0.83)O3

SAMPLE #: AF_41

COMMENTS: mfg. by A-T Research

PROPERTY	UNITS	COEFFICIENTS A	B	C	D	R^2	TEMPERATURE, K MINIMUM	MAXIMUM
log sigma	1/(ohm-cm)	8.020E-01	3.905E+02	----	----	0.994	632	1187
		6.280E-01	1.956E+02	----	----	0.999	1186	1509
log(sigmaxK)	K/(ohm-cm)	4.179E+00	7.612E+02	----	----	0.999	632	1509
lambda	W/(m-K)	2.927E-01	2.355E-04	----	----	-----	---	----
S	uV/K	5.032E+02	-4.950E-01	4.619E-04	-1.327E-07	0.567	603	1385

CALCULATED THERMOELECTRIC PROPERTIES

	Temperature K	log sigma 1/(ohm-cm)	log(sigmaxK) K/(ohm-cm)	lambda W/cm-K	S uV/K	Z 1/K	ZT
1	500	2.091E-02	2.657E+00	2.436E-02	3.546E+02	5.414E-06	2.707E-03
2	600	1.511E-01	2.910E+00	2.304E-02	3.438E+02	7.264E-06	4.358E-03
3	700	2.441E-01	3.092E+00	2.186E-02	3.375E+02	9.142E-06	6.399E-03
4	800	3.138E-01	3.227E+00	2.079E-02	3.348E+02	1.111E-05	8.889E-03
5	900	3.681E-01	3.333E+00	1.982E-02	3.351E+02	1.322E-05	1.190E-02
6	1000	4.115E-01	3.418E+00	1.893E-02	3.374E+02	1.550E-05	1.550E-02
7	1100	4.502E-01	3.487E+00	1.812E-02	3.409E+02	1.809E-05	1.989E-02
8	1200	4.650E-01	3.545E+00	1.738E-02	3.450E+02	1.998E-05	2.397E-02
9	1300	4.776E-01	3.593E+00	1.670E-02	3.487E+02	2.187E-05	2.843E-02

NOTES

1) Thermal conductivity data was estimated.

THERMOELECTRIC PROPERTIES

COMPOSITION: (La0.9,Ca0.1)(Al0.15,Cr0.85)O3

SAMPLE #: AF_42

COMMENTS: mfg. by General Refractories

PROPERTY	UNITS	COEFFICIENTS A	B	C	D	R^2	TEMPERATURE, K MINIMUM	MAXIMUM
log sigma	1/(ohm-cm)	1.301E+00	4.848E+02	----	----	0.994	581	1187
		1.068E+00	1.989E+02	----	----	0.934	1187	1507
log(sigmaxK)	K/(ohm-cm)	4.672E+00	8.471E+02	----	----	0.998	581	1507
lambda	W/(m-K)	2.927E-01	2.355E-04	----	----	-----	---	----
S	uV/K	1.424E+02	1.650E-01	-1.456E-04	5.239E-08	0.942	603	1324

CALCULATED THERMOELECTRIC PROPERTIES

	Temperature K	log sigma 1/(ohm-cm)	log(sigmaxK) K/(ohm-cm)	lambda W/cm-K	S uV/K	Z 1/K	ZT
1	500	3.315E-01	2.978E+00	2.436E-02	1.950E+02	3.348E-06	1.674E-03
2	600	4.931E-01	3.260E+00	2.304E-02	2.003E+02	5.416E-06	3.250E-03
3	700	6.085E-01	3.462E+00	2.186E-02	2.045E+02	7.766E-06	5.436E-03
4	800	6.951E-01	3.613E+00	2.079E-02	2.080E+02	1.031E-05	8.250E-03
5	900	7.624E-01	3.731E+00	1.982E-02	2.111E+02	1.301E-05	1.171E-02
6	1000	8.162E-01	3.825E+00	1.893E-02	2.141E+02	1.587E-05	1.587E-02
7	1100	8.872E-01	3.902E+00	1.812E-02	2.174E+02	2.011E-05	2.213E-02
8	1200	9.023E-01	3.966E+00	1.738E-02	2.212E+02	2.248E-05	2.698E-02
9	1300	9.150E-01	4.020E+00	1.670E-02	2.259E+02	2.513E-05	3.266E-02

NOTES

1) Thermal conductivity data was estimated.

THERMOELECTRIC PROPERTIES

COMPOSITION: 30m/oPrO2,70m/oZrO2

SAMPLE #: FCCP166

COMMENTS:

PROPERTY	UNITS	COEFFICIENTS A	B	C	D	R^2	TEMPERATURE, K MINIMUM	MAXIMUM
log sigma	1/(ohm-cm)	2.751E+00	5.443E+03	----	----	0.995	585	1555
log(sigmaxK)	K/(ohm-cm)	----	----	----	----	-----	---	----
lambda	W/(m-K)	5.000E-01	----	----	----	-----	---	----
S	uV/K	-1.305E+02	1.399E+00	-1.051E-03	2.439E-07	0.426	816	1383

CALCULATED THERMOELECTRIC PROPERTIES

	Temperature K	log sigma 1/(ohm-cm)	log(sigmaxK) K/(ohm-cm)	lambda W/cm-K	S uV/K	Z 1/K	ZT
1	700	-5.025E+00	-2.180E+00	2.000E-02	4.175E+02	8.227E-11	5.759E-08
2	800	-4.053E+00	-1.150E+00	2.000E-02	4.410E+02	8.605E-10	6.884E-07
3	900	-3.297E+00	-3.428E-01	2.000E-02	4.551E+02	5.226E-09	4.704E-06
4	1000	-2.692E+00	3.077E-01	2.000E-02	4.615E+02	2.163E-08	2.163E-05
5	1100	-2.197E+00	8.440E-01	2.000E-02	4.614E+02	6.755E-08	7.431E-05
6	1200	-1.785E+00	1.294E+00	2.000E-02	4.564E+02	1.708E-07	2.050E-04
7	1300	-1.436E+00	1.678E+00	2.000E-02	4.479E+02	3.675E-07	4.777E-04
8	1400	-1.137E+00	2.009E+00	2.000E-02	4.375E+02	6.979E-07	9.770E-04

NOTES

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1) log(sigmaxK) was calculated from log sigma and temperature calculated data.
2) Thermal conductivity data was estimated.

THERMOELECTRIC PROPERTIES

COMPOSITION: 49m/oIn2O3,19.9m/oPrO2,31.1m/oZrO2

SAMPLE #: FCCP54

COMMENTS:

PROPERTY	UNITS	COEFFICIENTS A	B	C	D	R²	TEMPERATURE, K MINIMUM	MAXIMUM
log sigma	1/(ohm-cm)	6.940E-01	3.066E+03	----	----	0.997	610	1547
log(sigmaxK)	K/(ohm-cm)	----	----	----	----	-----	---	----
lambda	W/(m-K)	5.000E-01	----	----	----	-----	---	----
S	uV/K	3.154E+03	-7.023E+00	5.917E-03	-1.654E-06	0.384	1136	1410

CALCULATED THERMOELECTRIC PROPERTIES

	Temperature K	log sigma 1/(ohm-cm)	log(sigmaxK) K/(ohm-cm)	lambda W/cm-K	S uV/K	Z 1/K	ZT
1	1000	-2.372E+00	6.285E-01	2.000E-02	4.041E+02	3.471E-08	3.471E-05
2	1100	-2.093E+00	9.486E-01	2.000E-02	3.969E+02	6.361E-08	6.997E-05
3	1200	-1.861E+00	1.219E+00	2.000E-02	3.989E+02	1.097E-07	1.316E-04
4	1300	-1.664E+00	1.450E+00	2.000E-02	4.001E+02	1.735E-07	2.255E-04
5	1400	-1.496E+00	1.650E+00	2.000E-02	3.907E+02	2.437E-07	3.412E-04

NOTES

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1) log(sigmaxK) was calculated from log sigma and temperature calculated data.
2) Thermal conductivity data was estimated.

THERMOELECTRIC PROPERTIES

COMPOSITION: 75m/oIn2O3.25m/oZrO2

SAMPLE #: FCCP144

COMMENTS:

PROPERTY	UNITS	COEFFICIENTS A	B	C	D	R²	TEMPERATURE, K MINIMUM	MAXIMUM
log sigma	1/(ohm-cm)	2.260E+00	9.843E+01	----	----	0.950	663	1079
		3.513E+00	1.449E+03	----	----	0.977	1079	1542
log(sigmaxK)	K/(ohm-cm)	----	----	----	----	-----	---	----
lambda	W/(m-K)	5.000E-01	----	----	----	-----	---	----
S	uV/K	1.830E+02	-6.320E-01	4.288E-04	-8.760E-08	0.881	932	1428

CALCULATED THERMOELECTRIC PROPERTIES

	Temperature K	log sigma 1/(ohm-cm)	log(sigmaxK) K/(ohm-cm)	lambda W/cm-K	S uV/K	Z 1/K	ZT
1	800	2.137E+00	5.040E+00	2.000E-02	-9.304E+01	5.933E-05	4.746E-02
2	900	2.151E+00	5.105E+00	2.000E-02	-1.024E+02	7.410E-05	6.669E-02
3	1000	2.064E+00	5.064E+00	2.000E-02	-1.078E+02	6.730E-05	6.730E-02
4	1100	2.195E+00	5.237E+00	2.000E-02	-1.100E+02	9.483E-05	1.043E-01
5	1200	2.305E+00	5.384E+00	2.000E-02	-1.093E+02	1.207E-04	1.448E-01
6	1300	2.398E+00	5.512E+00	2.000E-02	-1.064E+02	1.416E-04	1.841E-01
7	1400	2.473E+00	5.624E+00	2.000E-02	-1.017E+02	1.555E-04	2.177E-01

NOTES

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1) log(sigmaxK) was calculated from log sigma and temperature calculated data.
2) Thermal conductivity data was estimated.

THERMOELECTRIC PROPERTIES

COMPOSITION: 19.2m o/In2O3.58.7m/oPrO2.23.1m/oZrO2

SAMPLE #: FCCP160

COMMENTS:

PROPERTY	UNITS	COEFFICIENTS A	B	C	D	R^2	TEMPERATURE, K MINIMUM	MAXIMUM
log sigma	1/(ohm-cm)	-1.330E-01	2.562E+03	----	----	0.998	552	1390
		2.076E+00	5.574E+03	----	----	0.997	1390	1537
log(sigmaxK)	K/(ohm-cm)	----	----	----	----	-----	---	----
lambda	W/(m-K)	5.000E-01	----	----	----	-----	---	----
S	uV/K	5.363E+01	-3.190E-01	1.733E-04	-2.193E-08	0.992	577	1393

CALCULATED THERMOELECTRIC PROPERTIES

	Temperature K	log sigma 1/(ohm-cm)	log(sigmaxK) K/(ohm-cm)	lambda W/cm-K	S uV/K	Z 1/K	ZT
1	500	-5.258E+00	-2.559E+00	2.000E-02	-6.526E+01	1.177E-12	5.885E-10
2	600	-4.404E+00	-1.626E+00	2.000E-02	-8.012E+01	1.267E-11	7.602E-09
3	700	-3.794E+00	-9.485E-01	2.000E-02	-9.227E+01	6.848E-11	4.793E-08
4	800	-3.336E+00	-4.329E-01	2.000E-02	-1.019E+02	2.394E-10	1.915E-07
5	900	-2.980E+00	-2.587E-02	2.000E-02	-1.091E+02	6.228E-10	5.605E-07
6	1000	-2.695E+00	3.046E-01	2.000E-02	-1.140E+02	1.310E-09	1.310E-06
7	1100	-2.462E+00	5.789E-01	2.000E-02	-1.168E+02	2.350E-09	2.585E-06
8	1200	-2.268E+00	8.108E-01	2.000E-02	-1.175E+02	3.722E-09	4.467E-06
9	1300	-2.211E+00	9.026E-01	2.000E-02	-1.164E+02	4.162E-09	5.410E-06
10	1400	-1.905E+00	1.241E+00	2.000E-02	-1.135E+02	8.010E-09	1.121E-05

NOTES

1) log(sigmaxK) was calculated from log sigma and temperature calculated data.
2) Thermal conductivity data was estimated.

THERMOELECTRIC PROPERTIES

COMPOSITION: 20.1m/oIn2O3.39.6m/oPrO2.40.2m/oZrO2

SAMPLE #: FCCP93

COMMENTS:

PROPERTY	UNITS	COEFFICIENTS A	B	C	D	R^2	TEMPERATURE, K MINIMUM	MAXIMUM
log sigma	1/(ohm-cm)	-2.360E-01	4.483E+02	----	----	0.999	551	883
		2.525E+00	2.689E+03	----	----	0.981	883	1547
log(sigmaxK)	K/(ohm-cm)	----	----	----	----	-----	---	----
lambda	W/(m-K)	5.000E-01	----	----	----	-----	---	----
S	uV/K	8.390E+01	-4.888E-01	3.790E-04	-9.207E-08	0.969	535	1377

CALCULATED THERMOELECTRIC PROPERTIES

	Temperature K	log sigma 1/(ohm-cm)	log(sigmaxK) K/(ohm-cm)	lambda W/cm-K	S uV/K	Z 1/K	ZT
1	500	-1.133E+00	1.566E+00	2.000E-02	-7.726E+01	2.199E-08	1.100E-05
2	600	-9.831E-01	1.795E+00	2.000E-02	-9.283E+01	4.479E-08	2.687E-05
3	700	-8.764E-01	1.969E+00	2.000E-02	-1.041E+02	7.206E-08	5.045E-05
4	800	-8.357E-01	2.067E+00	2.000E-02	-1.117E+02	9.111E-08	7.289E-05
5	900	-4.623E-01	2.492E+00	2.000E-02	-1.161E+02	2.327E-07	2.094E-04
6	1000	-1.635E-01	2.836E+00	2.000E-02	-1.180E+02	4.775E-07	4.775E-04
7	1100	8.088E-02	3.122E+00	2.000E-02	-1.177E+02	8.350E-07	9.185E-04
8	1200	2.846E-01	3.364E+00	2.000E-02	-1.160E+02	1.295E-06	1.555E-03
9	1300	4.569E-01	3.571E+00	2.000E-02	-1.133E+02	1.838E-06	2.390E-03
10	1400	6.046E-01	3.751E+00	2.000E-02	-1.102E+02	2.444E-06	3.422E-03

NOTES

1) log(sigmaxK) was calculated from log sigma and temperature calculated data.
2) Thermal conductivity data was estimated.

THERMOELECTRIC PROPERTIES

COMPOSITION: 23m/oIn2O3.34.3m/oPrO2.42.7m/oZrO2

SAMPLE #: FCCP52

COMMENTS:

PROPERTY	UNITS	COEFFICIENTS A	B	C	D	R^2	TEMPERATURE, K MINIMUM	MAXIMUM
log sigma	1/(ohm-cm)	1.220E+00	1.411E+03	----	----	0.970	566	817
		2.691E+00	2.582E+03	----	----	0.997	817	1556
log(sigmaxK)	K/(ohm-cm)	----	----	----	----	-----	---	----
lambda	W/(m-K)	5.000E-01	----	----	----	-----	---	----
S	uV/K	2.184E+01	-2.311E-01	1.010E-04	-4.301E-09	0.988	556	1378

CALCULATED THERMOELECTRIC PROPERTIES

	Temperature K	log sigma 1/(ohm-cm)	log(sigmaxK) K/(ohm-cm)	lambda W/cm-K	S uV/K	Z 1/K	ZT
1	500	-1.603E+00	1.096E+00	2.000E-02	-6.899E+01	5.940E-09	2.970E-06
2	600	-1.132E+00	1.646E+00	2.000E-02	-8.139E+01	2.442E-08	1.465E-05
3	700	-9.974E-01	1.848E+00	2.000E-02	-9.191E+01	4.249E-08	2.974E-05
4	800	-5.364E-01	2.367E+00	2.000E-02	-1.006E+02	1.472E-07	1.177E-04
5	900	-1.778E-01	2.776E+00	2.000E-02	-1.075E+02	3.835E-07	3.452E-04
6	1000	1.091E-01	3.109E+00	2.000E-02	-1.126E+02	8.143E-07	8.143E-04
7	1100	3.438E-01	3.385E+00	2.000E-02	-1.159E+02	1.482E-06	1.630E-03
8	1200	5.394E-01	3.619E+00	2.000E-02	-1.175E+02	2.389E-06	2.867E-03
9	1300	7.049E-01	3.819E+00	2.000E-02	-1.173E+02	3.490E-06	4.537E-03
10	1400	8.468E-01	3.993E+00	2.000E-02	-1.155E+02	4.690E-06	6.566E-03

NOTES

1) log(sigmaxK) was calculated from log sigma and temperature calculated data.
2) Thermal conductivity data was estimated.

THERMOELECTRIC PROPERTIES

COMPOSITION: 36.6m/oIn2O3,28.6m/oPrO2,34.8m/oZrO2

SAMPLE #: FCCP51

COMMENTS:

PROPERTY	UNITS	COEFFICIENTS A	B	C	D	R²	TEMPERATURE, K MINIMUM	MAXIMUM
log sigma	1/(ohm-cm)	1.911E+00	8.635E+02	----	----	0.978	539	766
		3.465E+00	2.065E+03	----	----	0.994	766	1565
log(sigmaxK)	K/(ohm-cm)	----	----	----	----	-----	---	----
lambda	W/(m-K)	5.000E-01	----	----	----	-----	---	----
S	uV/K	7.600E+00	-1.640E-01	-1.254E-05	5.291E-08	0.992	484	1221

CALCULATED THERMOELECTRIC PROPERTIES

	Temperature K	log sigma 1/(ohm-cm)	log(sigmaxK) K/(ohm-cm)	lambda W/cm-K	S uV/K	Z 1/K	ZT
1	500	1.841E-01	2.883E+00	2.000E-02	-7.092E+01	3.842E-07	1.921E-04
2	600	4.719E-01	3.250E+00	2.000E-02	-8.389E+01	1.043E-06	6.257E-04
3	700	5.150E-01	3.360E+00	2.000E-02	-9.520E+01	1.483E-06	1.038E-03
4	800	8.838E-01	3.787E+00	2.000E-02	-1.045E+02	4.181E-06	3.345E-03
5	900	1.171E+00	4.125E+00	2.000E-02	-1.116E+02	9.221E-06	8.299E-03
6	1000	1.400E+00	4.400E+00	2.000E-02	-1.160E+02	1.691E-05	1.691E-02
7	1100	1.588E+00	4.629E+00	2.000E-02	-1.176E+02	2.674E-05	2.941E-02
8	1200	1.744E+00	4.823E+00	2.000E-02	-1.158E+02	3.722E-05	4.467E-02

NOTES

1) log(sigmaxK) was calculated from log sigma and temperature calculated data.
2) Thermal conductivity data was estimated.

THERMOELECTRIC PROPERTIES

COMPOSITION: 11.2m/oIn2O3,88.8m/oSnO2

SAMPLE #: FC_56

COMMENTS:

PROPERTY	UNITS	COEFFICIENTS A	B	C	D	R^2	TEMPERATURE, K MINIMUM	MAXIMUM
log sigma	1/(ohm-cm)	1.476E+00	8.231E+02	----	----	0.980	613	1111
log(sigmaxK)	K/(ohm-cm)	----	----	----	----	-----	---	----
lambda	W/(m-K)	4.249E-02	2.503E-04	----	----	0.910	563	1101
S	uV/K	5.899E+01	-2.277E-01	9.738E-05	-2.292E-09	0.986	601	1335

CALCULATED THERMOELECTRIC PROPERTIES

	Temperature K	log sigma 1/(ohm-cm)	log(sigmaxK) K/(ohm-cm)	lambda W/cm-K	S uV/K	Z 1/K	ZT
1	500	-1.702E-01	2.529E+00	5.964E-02	-3.081E+01	1.075E-08	5.376E-06
2	600	1.042E-01	2.882E+00	5.190E-02	-4.307E+01	4.544E-08	2.727E-05
3	700	3.001E-01	3.145E+00	4.593E-02	-5.348E+01	1.243E-07	8.700E-05
4	800	4.471E-01	3.350E+00	4.119E-02	-6.203E+01	2.615E-07	2.092E-04
5	900	5.614E-01	3.516E+00	3.734E-02	-6.875E+01	4.610E-07	4.149E-04
6	1000	6.529E-01	3.653E+00	3.415E-02	-7.364E+01	7.140E-07	7.140E-04
7	1100	7.277E-01	3.769E+00	3.146E-02	-7.672E+01	9.994E-07	1.099E-03

NOTES

1) log(sigmaxK) was calculated from log sigma and temperature calculated data.

THERMOELECTRIC PROPERTIES

COMPOSITION: 16.3m/oIn2O3,83.6m/oSnO2

SAMPLE #: FC_57

COMMENTS:

PROPERTY	UNITS	COEFFICIENTS A	B	C	D	R^2	TEMPERATURE, K MINIMUM	MAXIMUM
log sigma	1/(ohm-cm)	1.409E+00	1.155E+03	----	----	0.999	606	961
log(sigmaxK)	K/(ohm-cm)	----	----	----	----	-----	---	----
lambda	W/(m-K)	1.943E-01	1.982E-04	----	----	0.720	618	1088
S	uV/K	-9.807E+00	-2.660E-02	-9.322E-05	5.899E-08	0.994	607	1312

CALCULATED THERMOELECTRIC PROPERTIES

	Temperature K	log sigma 1/(ohm-cm)	log(sigmaxK) K/(ohm-cm)	lambda W/cm-K	S uV/K	Z 1/K	ZT
1	500	-9.010E-01	1.798E+00	3.408E-02	-3.904E+01	5.616E-09	2.808E-06
2	600	-5.160E-01	2.262E+00	3.193E-02	-4.659E+01	2.072E-08	1.243E-05
3	700	-2.410E-01	2.604E+00	3.003E-02	-5.387E+01	5.549E-08	3.884E-05
4	800	-3.475E-02	2.868E+00	2.834E-02	-6.055E+01	1.194E-07	9.552E-05
5	900	1.257E-01	3.080E+00	2.683E-02	-6.625E+01	2.185E-07	1.966E-04
6	1000	2.540E-01	3.254E+00	2.548E-02	-7.064E+01	3.515E-07	3.515E-04

NOTES

1) log(sigmaxK) was calculated from log sigma and temperature calculated data.

THERMOELECTRIC PROPERTIES

COMPOSITION: 30.6m/oIn2O3,69.4SnO2

SAMPLE #: FC_59

COMMENTS:

PROPERTY	UNITS	COEFFICIENTS A	B	C	D	R^2	TEMPERATURE, K MINIMUM	MAXIMUM
log sigma	1/(ohm-cm)	2.142E+00	-2.715E+02	----	----	0.980	1331	1731
		2.751E+00	8.670E+02	----	----	0.940	708	1148
log(sigmaxK)	K/(ohm-cm)	----	----	----	----	-----	---	----
lambda	W/(m-K)	1.943E-01	1.982E-04	----	----	-----	---	----
S	uV/K	-1.930E+01	1.552E-02	-1.104E-04	5.332E-08	0.998	609	1333

CALCULATED THERMOELECTRIC PROPERTIES

	Temperature K	log sigma 1/(ohm-cm)	log(sigmaxK) K/(ohm-cm)	lambda W/cm-K	S uV/K	Z 1/K	ZT
1	600	1.306E+00	4.084E+00	3.193E-02	-3.821E+01	9.254E-07	5.552E-04
2	700	1.512E+00	4.358E+00	3.003E-02	-4.424E+01	2.121E-06	1.485E-03
3	800	1.667E+00	4.570E+00	2.834E-02	-5.024E+01	4.140E-06	3.312E-03
4	900	1.788E+00	4.742E+00	2.683E-02	-5.589E+01	7.138E-06	6.425E-03
5	1000	1.884E+00	4.884E+00	2.548E-02	-6.086E+01	1.113E-05	1.113E-02
6	1100	1.963E+00	5.004E+00	2.425E-02	-6.484E+01	1.591E-05	1.751E-02
7	1200	2.368E+00	5.447E+00	2.314E-02	-6.752E+01	4.599E-05	5.519E-02
8	1300	2.351E+00	5.465E+00	2.213E-02	-6.856E+01	4.765E-05	6.194E-02

NOTES
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1) log(sigmaxK) was calculated from log sigma and temperature calculated data.
2) Thermal conductivity data was estimated.

THERMOELECTRIC PROPERTIES

COMPOSITION: 40m/oIn2O3,60m/oSnO2

SAMPLE #: FC_125

COMMENTS:

PROPERTY	UNITS	COEFFICIENTS A	B	C	D	R²	TEMPERATURE, K MINIMUM	MAXIMUM
log sigma	1/(ohm-cm)	2.581E+00	3.586E+02	----	----	0.990	663	1517
log(sigmaxK)	K/(ohm-cm)	----	----	----	----	-----	---	----
lambda	W/(m-K)	1.943E-01	1.982E-04	----	----	-----	---	----
S	uV/K	3.304E+01	-2.150E-01	9.859E-05	-1.698E-08	0.990	503	1343

CALCULATED THERMOELECTRIC PROPERTIES

	Temperature K	log sigma 1/(ohm-cm)	log(sigmaxK) K/(ohm-cm)	lambda W/cm-K	S uV/K	Z 1/K	ZT
1	600	1.983E+00	4.761E+00	3.193E-02	-6.416E+01	1.241E-05	7.446E-03
2	700	2.069E+00	4.914E+00	3.003E-02	-7.501E+01	2.195E-05	1.537E-02
3	800	2.133E+00	5.036E+00	2.834E-02	-8.460E+01	3.428E-05	2.743E-02
4	900	2.183E+00	5.137E+00	2.683E-02	-9.303E+01	4.910E-05	4.419E-02
5	1000	2.222E+00	5.222E+00	2.548E-02	-1.004E+02	6.603E-05	6.603E-02
6	1100	2.255E+00	5.296E+00	2.425E-02	-1.068E+02	8.464E-05	9.310E-02
7	1200	2.282E+00	5.361E+00	2.314E-02	-1.124E+02	1.045E-04	1.255E-01
8	1300	2.305E+00	5.419E+00	2.213E-02	-1.172E+02	1.254E-04	1.630E-01

NOTES

1) log(sigmaxK) was calculated from log sigma and temperature calculated data.
2) Thermal conductivity data was estimated.

THERMOELECTRIC PROPERTIES

COMPOSITION: 50m/oIn2O3,50m/oSnO2

SAMPLE #: FC_97_7

COMMENTS:

PROPERTY	UNITS	COEFFICIENTS A	B	C	D	R^2	TEMPERATURE, K MINIMUM	MAXIMUM
log sigma	1/(ohm-cm)	2.457E+00	2.156E+00	----	----	0.900	711	1676
log(sigmaxK)	K/(ohm-cm)	----	----	----	----	-----	---	----
lambda	W/(m-K)	1.943E-01	1.982E-04	----	----	-----	---	----
S	uV/K	-7.295E+00	-8.054E-02	-2.971E-05	2.801E-08	0.999	471	1341

CALCULATED THERMOELECTRIC PROPERTIES

	Temperature K	log sigma 1/(ohm-cm)	log(sigmaxK) K/(ohm-cm)	lambda W/cm-K	S uV/K	Z 1/K	ZT
1	600	2.453E+00	5.232E+00	3.193E-02	-6.026E+01	3.231E-05	1.939E-02
2	700	2.454E+00	5.299E+00	3.003E-02	-6.862E+01	4.460E-05	3.122E-02
3	800	2.454E+00	5.357E+00	2.834E-02	-7.639E+01	5.862E-05	4.689E-02
4	900	2.455E+00	5.409E+00	2.683E-02	-8.342E+01	7.387E-05	6.648E-02
5	1000	2.455E+00	5.455E+00	2.548E-02	-8.953E+01	8.966E-05	8.966E-02
6	1100	2.455E+00	5.496E+00	2.425E-02	-9.455E+01	1.051E-04	1.156E-01
7	1200	2.455E+00	5.534E+00	2.314E-02	-9.831E+01	1.191E-04	1.430E-01
8	1300	2.455E+00	5.569E+00	2.213E-02	-1.007E+02	1.307E-04	1.698E-01

NOTES

1) log(sigmaxK) was calculated from log sigma and temperature calculated data.
2) Thermal conductivity data was estimated.

THERMOELECTRIC PROPERTIES

COMPOSITION: 60m/oIn2O3,40m/oSnO2

SAMPLE #: FC_126

COMMENTS:

PROPERTY	UNITS	COEFFICIENTS A	B	C	D	R^2	TEMPERATURE, K MINIMUM	MAXIMUM
log sigma	1/(ohm-cm)	3.054E+00	5.427E+02	----	----	0.980	1281	1675
		2.619E+00	----	----	----	0.000	625	1281
log(sigmaxK)	K/(ohm-cm)	----	----	----	----	-----	---	----
lambda	W/(m-K)	1.943E-01	1.982E-04	----	----	-----	---	----
S	uV/K	-7.422E+01	2.249E-01	-3.937E-04	1.618E-07	0.995	613	1252

CALCULATED THERMOELECTRIC PROPERTIES

	Temperature K	log sigma 1/(ohm-cm)	log(sigmaxK) K/(ohm-cm)	lambda W/cm-K	S uV/K	Z 1/K	ZT
1	500	2.619E+00	5.318E+00	3.408E-02	-3.997E+01	1.950E-05	9.748E-03
2	600	2.619E+00	5.397E+00	3.193E-02	-4.606E+01	2.764E-05	1.658E-02
3	700	2.619E+00	5.464E+00	3.003E-02	-5.421E+01	4.070E-05	2.849E-02
4	800	2.619E+00	5.522E+00	2.834E-02	-6.343E+01	5.904E-05	4.723E-02
5	900	2.619E+00	5.573E+00	2.683E-02	-7.275E+01	8.205E-05	7.384E-02
6	1000	2.619E+00	5.619E+00	2.548E-02	-8.122E+01	1.077E-04	1.077E-01
7	1100	2.619E+00	5.660E+00	2.425E-02	-8.785E+01	1.324E-04	1.456E-01
8	1200	2.619E+00	5.698E+00	2.314E-02	-9.145E+01	1.511E-04	1.813E-01
9	1300	2.619E+00	5.733E+00	2.213E-02	-9.173E+01	1.582E-04	2.056E-01

NOTES
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1) log(sigmaxK) was calculated from log sigma and temperature calculated data.
2) Thermal conductivity data was estimated.

THERMOELECTRIC PROPERTIES

COMPOSITION: 70m/oIn2o3.30m/oSnO2

SAMPLE #: FC_97_9

COMMENTS:

PROPERTY	UNITS	COEFFICIENTS A	B	C	D	R^2	TEMPERATURE, K MINIMUM	MAXIMUM
log sigma	1/(ohm-cm)	2.663E+00	-1.521E+02	----	----	0.850	597	1100
		3.291E+00	5.307E+02	----	----	0.960	1100	1541
log(sigmaxK)	K/(ohm-cm)	----	----	----	----	-----	---	----
lambda	w/(m-K)	2.121E-01	1.239E-04	----	----	0.241	500	1291
S	uV/K	7.346E+01	-3.028E-01	1.962E-04	-4.217E-08	0.994	610	1326

CALCULATED THERMOELECTRIC PROPERTIES

	Temperature K	log sigma 1/(ohm-cm)	log(sigmaxK) K/(ohm-cm)	lambda W/cm-K	S uV/K	Z 1/K	ZT
1	500	2.967E+00	5.666E+00	3.650E-02	-3.416E+01	2.965E-05	1.482E-02
2	600	2.917E+00	5.695E+00	3.492E-02	-4.670E+01	5.153E-05	3.092E-02
3	700	2.880E+00	5.725E+00	3.347E-02	-5.683E+01	7.324E-05	5.126E-02
4	800	2.853E+00	5.756E+00	3.214E-02	-6.480E+01	9.317E-05	7.454E-02
5	900	2.832E+00	5.786E+00	3.091E-02	-7.088E+01	1.104E-04	9.936E-02
6	1000	2.760E+00	5.760E+00	2.977E-02	-7.531E+01	1.097E-04	1.097E-01
7	1100	2.809E+00	5.850E+00	2.871E-02	-7.835E+01	1.376E-04	1.513E-01
8	1200	2.849E+00	5.928E+00	2.772E-02	-8.024E+01	1.639E-04	1.967E-01
9	1300	2.883E+00	5.997E+00	2.680E-02	-8.125E+01	1.880E-04	2.444E-01

NOTES

1) log(sigmaxK) was calculated from log sigma and temperature calculated data.

THERMOELECTRIC PROPERTIES

COMPOSITION: 80m/oIn2O3,20m/oSnO2

SAMPLE #: FC_97_10

COMMENTS:

PROPERTY	UNITS	COEFFICIENTS A	B	C	D	R^2	TEMPERATURE, K MINIMUM	MAXIMUM
log sigma	1/(ohm-cm)	3.040E+00	-7.582E+01	----	----	0.500	585	1578
log(sigmaxK)	K/(ohm-cm)	----	----	----	----	-----	---	----
lambda	W/(m-K)	1.842E-01	-9.460E-05	----	----	0.340	468	1088
S	uV/K	-2.980E+01	3.315E-02	-7.049E-05	2.565E-08	0.997	479	1424

CALCULATED THERMOELECTRIC PROPERTIES

	Temperature K	log sigma 1/(ohm-cm)	log(sigmaxK) K/(ohm-cm)	lambda W/cm-K	S uV/K	Z 1/K	ZT
1	500	3.192E+00	5.891E+00	7.304E-02	-2.764E+01	1.627E-05	8.133E-03
2	600	3.166E+00	5.945E+00	7.846E-02	-2.975E+01	1.654E-05	9.927E-03
3	700	3.148E+00	5.993E+00	8.475E-02	-3.234E+01	1.736E-05	1.215E-02
4	800	3.135E+00	6.038E+00	9.213E-02	-3.526E+01	1.841E-05	1.472E-02
5	900	3.124E+00	6.078E+00	1.009E-01	-3.836E+01	1.941E-05	1.747E-02
6	1000	3.116E+00	6.116E+00	1.116E-01	-4.149E+01	2.014E-05	2.014E-02
7	1100	3.109E+00	6.150E+00	1.248E-01	-4.448E+01	2.038E-05	2.242E-02

NOTES

1) log(sigmaxK) was calculated from log sigma and temperature calculated data.

THERMOELECTRIC PROPERTIES

COMPOSITION: 90.2m/oIn2O3,9.8m/oSnO2

SAMPLE #: FC_160

COMMENTS:

PROPERTY	UNITS	COEFFICIENTS A	B	C	D	R^2	TEMPERATURE, K MINIMUM	MAXIMUM
log sigma	1/(ohm-cm)	2.675E+00	-1.250E-02	----	----	-----	---	----
log(sigmaxK)	K/(ohm-cm)	----	----	----	----	-----	---	----
lambda	W/(m-K)	1.943E-01	1.982E-04	----	----	-----	---	----
S	uV/K	-8.879E+01	2.549E-01	-3.777E-04	1.510E-07	0.998	607	1326

CALCULATED THERMOELECTRIC PROPERTIES

	Temperature K	log sigma 1/(ohm-cm)	log(sigmaxK) K/(ohm-cm)	lambda W/cm-K	S uV/K	Z 1/K	ZT
1	600	2.675E+00	5.453E+00	3.193E-02	-3.920E+01	2.277E-05	1.366E-02
2	700	2.675E+00	5.520E+00	3.003E-02	-4.363E+01	3.000E-05	2.100E-02
3	800	2.675E+00	5.578E+00	2.834E-02	-4.927E+01	4.054E-05	3.243E-02
4	900	2.675E+00	5.629E+00	2.683E-02	-5.522E+01	5.378E-05	4.840E-02
5	1000	2.675E+00	5.675E+00	2.548E-02	-6.057E+01	6.814E-05	6.814E-02
6	1100	2.675E+00	5.716E+00	2.425E-02	-6.441E+01	8.094E-05	8.904E-02
7	1200	2.675E+00	5.754E+00	2.314E-02	-6.584E+01	8.864E-05	1.064E-01
8	1300	2.675E+00	5.789E+00	2.213E-02	-6.395E+01	8.746E-05	1.137E-01

NOTES

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1) log(sigmaxK) was calculated from log sigma and temperature calculated data.
2) Thermal conductivity data was estimated.
3) Electrical conductivity was temperature independent.

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